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Research and technology for increasing the efficiency and output of lamb production systems

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Research and technology for increasing the efficiency and output of lamb production systems

L. AINSWORTH, D.P. HEANEY, P.S. FISER,
G.A. LANGFORD, J.N.B. SHRESTHA, D.A. LEGER
Animal Research Centre
Ottawa, Ontario

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cover
The dots on the map represent Agriculture Canada research establishments.

PREFACE

This Bulletin replaces the earlier Animal Research Centre (ARC) Technical Bulletin No. 2 entitled 'Research for an Intensive Total Confinement Sheep Production System' which was published in 1980.

The Bulletin summarizes the results of the sheep research program at ARC and presents in one place results that have been recorded in the scientific and technical literature over several years. In addition, it describes the potential for use by sheep producers of new technology and management strategies which have evolved or have been developed from the research program. The technology can be integrated as a whole, as has been done at ARC, or various components can be incorporated into alternative systems operating at various levels of intensification. As a result, Canadian sheep producers have several alternatives available to increase the efficiency, output and profitability of their lamb production systems.

In much of Canada it is necessary to provide housing and conserved forage for sheep during the long winters. Thus, only modest increases in facilities and equipment are required to provide year round housing. The experimental lamb production system at ARC permits the production of a uniform, year round supply of lamb and a level of ewe productivity which more than compensates for the cost of year round housing. It also eliminates costly programs for control of predators, internal and external parasites, and foot rot. Protection from the elements also provides for substantial savings in feed, increased feed efficiency, fewer days to market and cleaner wool.

The ability to produce a uniform, high quality product year round indicates a real potential for growth and expansion of the Canadian sheep industry. This could reduce substantially the level of imports of lamb, make it possible to increase domestic consumption and develop domestic and international specialty markets.

The Bulletin also includes a comprehensive bibliography for technical specialists who may want to refer to the original research publications. A selected list of additional reference material is provided for readers desiring more detailed background information.

April 1987

J.I. Elliot
A/Director
Animal Research Centre
Ottawa, Ontario
K1A 0C6

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DISCLAIMER

Mention of a trade name, proprietary product or specific equipment does not imply endorsement to the exclusion of other products or equipment which may be suitable and available.

SUMMARY

1. An integrated multidisciplinary research program was established at ARC in 1968 to develop and evaluate new technology for intensive lamb production using a systems approach. Major components include genetics, nutrition, reproductive physiology, housing, management, flock health, economics and computerized data handling.

2. Genetics and breeding studies have led to:
   - the development from domestic and imported breeds, of synthetic strains of sheep with the potential to provide a high economic return under intensive production.
   - a selection program, based on sound genetic principles, to increase growth rate and lean meat yield in a synthetic sire strain and reproductive performance in two synthetic dam strains.
   - crossbreeding evaluation of the synthetic strains, to provide information on the use of breed differences and selection for genetic improvement and of hybrid vigor to increase productivity.
   - a better understanding of genetic principles associated with high output lamb production systems.

3. Nutrition and management studies have produced:
   - an effective lamb rearing system based on early weaning and use of milk replacer.
   - postweaning diets which allow lambs to achieve their maximum growth potential.
   - practical feeding programs based on conserved forage to meet the nutrient requirements of ewes under accelerated lamb production.

4. Reproductive physiology research has developed procedures for:
   - controlled reproduction using progestagen impregnated intravaginal sponges.
   - pregnancy diagnosis utilizing ultrasonic detectors.
   - removing seasonal constraints to breeding by application of artificial photoperiods.
   - collecting, evaluating, processing, storage and insemination of fresh and frozen ram semen.

5. An experimental lamb production system has evolved concurrently with the research. Innovations designed to increase productivity, reduce cost and/or increase efficiency are incorporated as new findings become available. Under the system the sheep are maintained in a controlled environment year round. Breeding ewes and rams are divided into two flocks which are bred alternately at 4 month intervals. The productivity of the flock clearly demonstrates that intensification combined with new technology and management strategies, substantially increases the efficiency and output of lamb production, compared to that achieved under more traditional extensive management.

6. The technology available to producers for increasing the efficiency and output of lamb production systems is described. Intensification combined with a high level of management ability and expertise are required to effectively use the technology available.

RÉSUMÉ

1. Un programme intégré de recherches pluridisciplinaires a été mis sur pied au C.R.Z. en 1968 pour mettre au point et évaluer selon la démarche-système de nouvelles techniques de production intensive d'agneaux. Les principales composantes du programme comprennent la génétique, la nutrition, la physiologie de la reproduction, le logement, la gestion, la santé du troupeau, l'économie et le traitement des données informatiques.

2. Les études de génétique et de reproduction ont abouti à:
   - la création, à partir de races canadiennes et importées, de lignées synthétiques de moutons capables d'assurer un rendement économique élevé en régime de production intensive.
   - la mise sur pied d'un programme de sélection reposant sur des principes génétiques valables en vue d'améliorer le croît et le rendement de viande maigre d'une lignée paternelle synthétique et la performance de reproduction de deux lignées maternelles synthétiques.
   - l'évaluation du croisement des lignées synthétiques pour fournir des données sur l'utilisation de la sélection et des différences raciales pour l'amélioration génétique, ainsi que de la vigueur hybride pour l'accroissement de la productivité.
   - une meilleure compréhension des principes génétiques reliés au rendement élevé des systèmes de production d'agneaux.

3. Les études de nutrition et de gestion ont produit:
   - un système efficace d'élevage des agneaux fondé sur le sevrage précoce et l'utilisation d'aliments d'allaitement.
   - des rations de post-sevrage permettant aux agneaux de réaliser leurs potentialités de croissance maximum.
   - des programmes pratiques d'alimentation reposant sur du fourrage conservé de façon à satisfaire les exigences nutritionnelles des brebis en régime de production accéléré d'agneaux.

4. La recherche sur la physiologie de la reproduction a produit des méthodes pour:
   - la maîtrise de la reproduction à l'aide d'éponges vaginales imprégnées de progestagène.
   - le diagnostic de gestation au moyen de sondes ultrasoniques.
   - la levée des contraintes saisonnières à la reproduction par le recours à des photopériodes artificielles.
   - la collecte, l'évaluation, le traitement et le stockage de sperme de bélier frais et congelé aux fins d'insémination.

5. Le système expérimental de production d'agneaux a évolué parallèlement aux travaux de recherches. Les innovations destinées à accroître la productivité, à réduire le coût ou à augmenter l'efficience sont intégrées à mesure que de nouveaux résultats deviennent disponibles. Dans ce régime, les moutons sont maintenus en ambiance contrôlée à longueur d'année. Les brebis et les béliers de reproduction sont partagés en deux

RÉSUMÉ suite

troupeaux mis à la reproduction tour à tour à quatre mois d'intervalle. La productivité du troupeau démontre clairement que la production intensive, conjuguée à de nouvelles techniques et stratégies de gestion, permet d'accroître substantiellement l'efficience et le rendement de la production d'agneaux comparativement à ceux réalisés en régime de conduite extensive plus traditionnelle.

6. Le bulletin décrit la technologie accessible aux producteurs pour accroître l'efficience et le rendement des systèmes de production d'agneaux. La production intensive, conjuguée à un niveau élevé de capacité de gestion et de technicité, est nécessaire pour utiliser efficacement la technologie disponible.

1. INTRODUCTION

Traditional sheep management has evolved under conditions favoring the seasonal production of one or two lambs per ewe. However, with a biological capacity of at least five lambs per pregnancy and a lambing interval of 6-8 months, the ewe has ample scope for increased annual productivity and efficiency.

In Canada, significant changes have taken place in the size of the national flock and trade patterns for sheep and lamb products. Since World War II the sheep population has declined steadily to a low of about 550 000 head in 1977[1]. Subsequently, this trend has reversed and the number of sheep and lambs has been increasing up to 4% annually. At the same time the level of imported lamb products from New Zealand and the United States has been increasing at the expense of frozen mutton products from Australia. These trends indicate an increasing demand for lamb and a real potential for growth and expansion of the Canadian sheep industry to meet domestic requirements. However, if the industry is to grow and compete effectively with other livestock species in converting limited resources into lean meat, new technology and management strategies which increase lamb production capability and efficiency need to be developed and used.

Research has demonstrated that productivity can be improved by using breeds with special characteristics such as high prolificacy, rapid growth rate and increased muscle mass. Further increases in performance are possible through specific crossbreeding schemes, selection within or between breeds and the mating of ewe lambs. Also, annual lamb output can be enhanced by applying innovative management techniques, such as artificial photoperiods and hormonal treatments which reduce or eliminate seasonal constraints to breeding and permit production of lamb crops every 6-8 months. Exploiting this higher productivity requires the development of effective procedures for artificial rearing, control of predators, parasites and disease, and nutrition programs to support the higher levels of production.

Research at the Animal Research Centre (ARC) has developed and evaluated technology and management strategies, based on the above concepts, which can substantially increase the efficiency and output of lamb production systems. Moreover, the technology is applicable to varying levels of intensification.. As a result, viable opportunities and alternatives are available to Canadian sheep producers for developing sound management options to increase the efficiency, output and profitability of their lamb production enterprises.

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[1]Livestock and Animal Products Statistics. Statistics Canada, Ottawa, Ont., Catalogue 23-203 Annual.

2. THE RESEARCH PROGRAM

In 1968 ARC initiated an innovative sheep research program using specialized research and production facilities. The long-term commitment of manpower, animals, capital and operating resources, together with the continuing support of Agriculture Canada's Research Branch and the Director of ARC, has enabled the Centre to provide and sustain a major contribution to the national research effort on sheep.

The rationale and experimental approach used in planning the research program have been described (21). Expertise from various disciplines was utilized. The mandate of the research program was to develop and evaluate technology and management strategies for high output lamb production systems, which could operate efficiently and profitably under Canadian conditions. A systems approach was used, in which the research was carried out and integrated with an experimental lamb production system, capable of producing a uniform supply of lambs under year round housing. Major research emphasis was placed on the development of techniques and procedures for optimal use of selection and crossbreeding to produce strains of sheep which give a high economic return under intensive and sustained lamb production, removal of seasonal constraints to breeding, decreasing the lambing interval, increasing litter size, use and application of artificial insemination, long term storage of ram semen, artificial rearing and optimizing the efficiency of growth of the market lamb. All of the studies are evaluated for their contribution and relevance to increasing the efficiency and/or output of the experimental production system. In instances where there is a requirement for more basic research to answer specific questions critical to the development of the overall research program, the studies are conducted in a separate, intensive research barn using animals separate from the production flock. Subsequently, encouraging results are validated by carefully superimposing experiments on the production flock.

2.1 GENETICS RESEARCH

The genetics and breeding research was established to develop specialized sire and dam strains adapted for use in an intensive crossbred lamb production system and, simultaneously, to assess the complex underlying genetic principles involved. Three distinct genetic strains, consisting of a sire strain and two dam strains, were developed from crossbred foundations. Pure strain selection was aimed at improving individual performance by using the genetic variation within each population. Selection indexes were used to increase lean growth in the synthetic sire strain and to improve reproductive performance in the two synthetic dam strains. To develop these indexes, a number of genetic parameters for economically important traits were estimated from the populations within the controlled environment.

It is not possible to conduct long term selection experiments, free from environmental influences, on the performance of selected populations. Therefore, unselected Suffolk and Finnish Landrace populations were established to separate progress due to selection from changes due to environment. Also, correlated responses of production characteristics other than those under selection can be evaluated.

Finally, recently initiated crossbreeding evaluation of the newly developed synthetic strains will provide valuable information on the use of breed differences and selection as a source of genetic improvement, and the benefits of crossbreeding to improve the efficiency of production. Although all lambs are reared artificially during strain development, the crossbreeding evaluations will be carried out in a conventional environment where milk yield of the ewe is particularly important to the lamb.

2.1.1 Foundation Stocks for Strain Development

In 1966 the ARC ewe flock consisted of approximately 160 Shropshires, 190 Suffolks and 90 ewes of a synthetic strain (OS) previously developed at Ottawa from the Leicester, North Country Cheviot, Romnelet and Suffolk breeds (approximately 25% contribution from each).

From 1966 through 1969, 16 Shropshire, 20 Suffolk and 18 OS rams were used for breeding. Groups of 12 ewes per ram were mated to produce both purebred and crossbred offspring from the Suffolks and Shropshires, whereas OS ewes were mated only to OS rams.

Financial restrictions made it impossible to purchase female breeding stock chosen especially for their genetic potential. Thus, to increase the flock size and broaden the genetic base, 513 ewes were transferred to ARC between 1968 and 1973, from a crossbreeding and selection program being carried out at the Agriculture Canada research establishments in Lennoxville and La Pocatière, Québec.

Foreign and other domestic breeds were investigated as potential sources of germplasm. Breeds with high growth rates and heavy muscling were needed for the sire strain and those with large litter size and long breeding season were required for the dam strains. The importation of breeds, such as the Romanov and Texel, from Continental Europe was not possible because of the inability to meet Canadian animal health requirements. Also, financial constraints allowed the purchase of only a few animals of each breed. Finally, the Ile de France (Figure 1A), a fast growing and heavily muscled sheep developed in France from Leicester X Merino crosses and available from Scotland, and the Lincoln were chosen to contribute desirable genes to the sire strain. The East Friesian (Figure 1B), also available from Scotland, and the Finnish Landrace (Figure 1C) were chosen to contribute to the two dam strains. The East Friesian is a large dairy breed from West Germany with an average of about two lambs per lambing. The Finnish Landrace reaches puberty at an early age (6-7 months) and excels in prolificacy (litters of four are common).

Between 1968 and 1971, five Finnish Landrace rams, eight pregnant Finnish Landrace ewes and three Lincoln rams were purchased in Canada. Eleven Ile de France rams and five East Friesian rams were imported from Scotland. These introductions and importations, together with the original ARC flock and the ewes transferred from Quebec, provided the foundation stocks for development of the synthetic strains.

Figure 1. Imported rams used in the development of the synthetic strains. (A) Ile de France, (B) East Friesian, (C) Finnish Landrace.

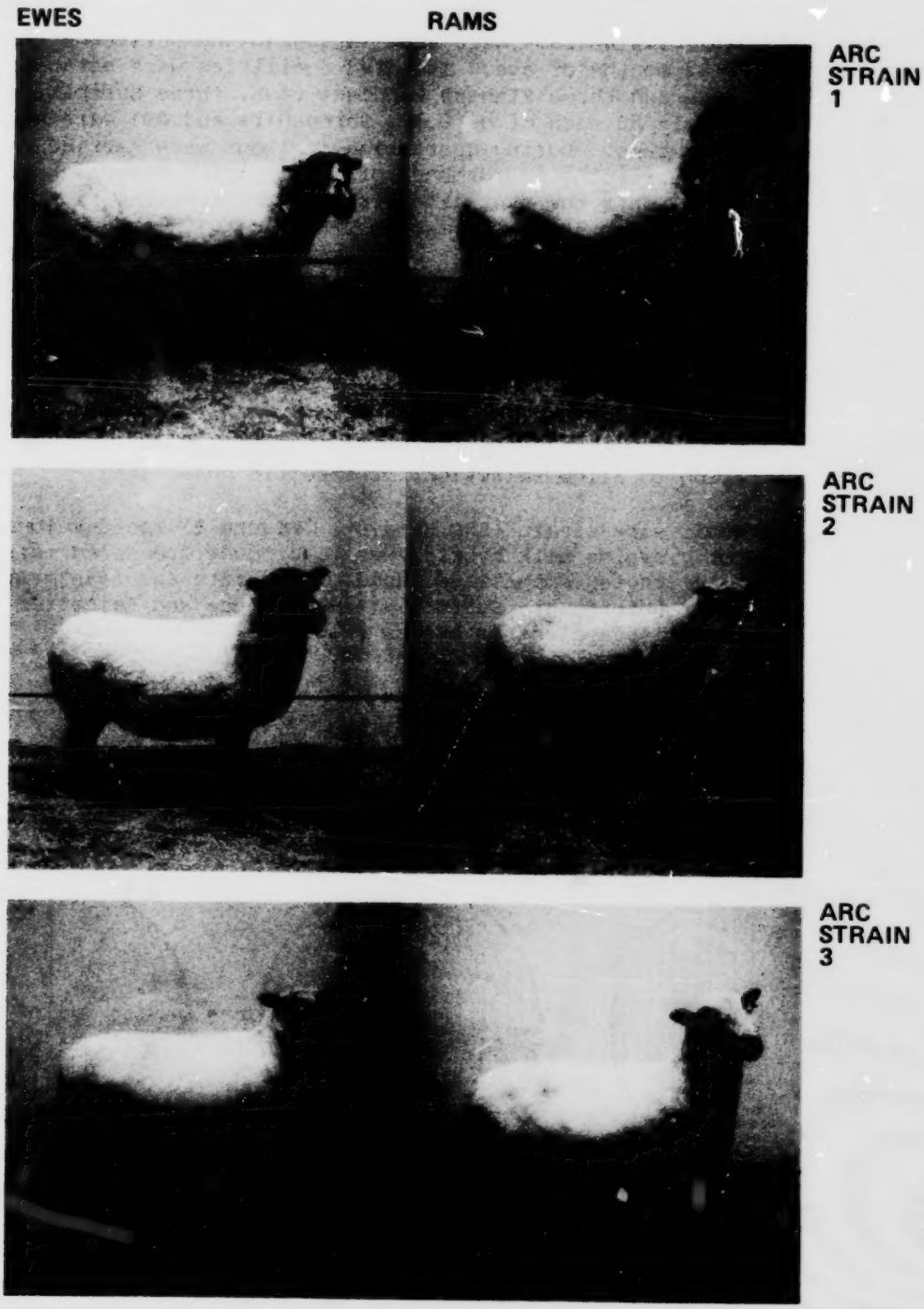

Figure 2. Synthetic strains developed at ARC.

Because of the presence of scrapie in Great Britain, the imported Ile de France and East Friesian rams were kept in quarantine until the first offspring were 42 months of age. Isolated facilities were established at the ARC Research Farm and three Finnish Landrace rams, three Suffolk rams and 240 ewes (approximately 80 each of Suffolk, Shropshire and OS) were housed along with the imported rams. During quarantine, matings were carried out to evaluate the crossbreeding performance of the imported breeds and to make the crosses needed to start the synthetic strains. At the same time, specific matings contributing to strain formation were made with the remainder of the flock, which was housed in the controlled environment barns. Following termination of the quarantine in the fall of 1974, the animals were combined in the controlled environment barns.

2.1.2 Synthesis of New Strains

Because of the quarantine and financial constraints the new strains could not be synthesized in a formal way, as would be done with laboratory animals. However, the number of breeds in the foundation stock provided sufficient genetic variation to allow selection for specific objectives.

The synthetic sire strain (ARC Strain 1; Figure 2) was developed as a meat type strain for crossing with hybrid ewes to produce crossbred market lambs. Hence, the breeds chosen emphasized rapid growth rate and lean meat yield. The primary contributors were Suffolk, Ile de France and Leicester with minor contributions from several other breeds (Figure 3).

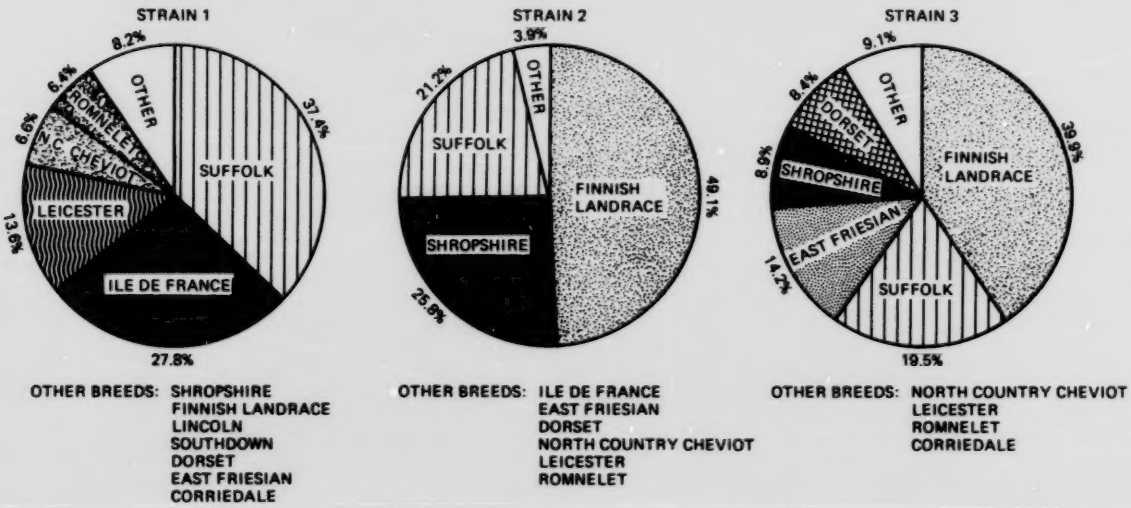

Figure 3. Breed composition of the synthetic strains in 1985.

High fertility and the potential for year round lambing received primary emphasis for the development of the two synthetic dam strains (ARC Strains 2 & 3: Figure 2). It was intended that each would contain approximately 50% Finnish Landrace ancestry. In addition, ARC Strain 2 would contain approximately equal contributions from the Suffolk and Shropshire breeds whereas ARC Strain 3 would have a broader genetic background with contributions from the Dorset, East Friesian, Shropshire and Suffolk breeds plus minor contributions from several others. Because of pedigree errors the breed composition of ARC Strains 1 and 2 included breeds other than was originally intended (Figure 3). Evaluation of these errors indicated they were of minor significance and they were allowed to remain.

The unselected Suffolk (ARC Strain 4) was derived from 20 original rams while the unselected Finnish Landrace (ARC Strain 5) was derived from eight original rams. In 1982, ARC Strain 6 was established from 20 sires of ARC Strain 3 as an unselected population for the dam strains. The unselected strains are being maintained to provide a broad representation of the foundation breeding stock.

In 1974, the synthetic strains were closed to the introduction of new genetic material. Thereafter, until 1977 the strains were expanded to reach target numbers. During this expansion phase there was minimal culling to permit the various breed cross combinations to stabilize and maintain as broad a genetic background as possible in each strain. Since 1977, the synthetic strains have been considered as homogeneous populations for the traits being selected. In 1986, the synthetic strains were 6-7 generations from the time when the populations were closed in 1974, with an inbreeding level of 2-3%.

Following the establishment of a minimal disease flock by hysterectomy in 1980 (see page 36), matings of the hysterectomy derived animals were designed to re-establish the original genetic base of the synthetic and control strains. The required numbers of rams and ewes were reached in 1983 (Table 1).

2.1.3 Mating System

In the selected strains, ewes were mated in the ratio of 10-12 ewes per ram until 1980. Since then the ratio has been reduced to eight ewes per ram. In the control strains the mating groups consist of two ewes per ram. All mating groups are designed to avoid related matings while breeding each ram to a representative sample of ewes from the strain. The use of rams over two successive breedings (repeat mating) ensures there are genetically similar progeny from some sires in two consecutive lambings. The careful choice of replacements in the control strains, to maintain a broad representation of originally assigned stocks, ensures minimal genetic change in these populations. When selected rams are assigned randomly to selected ewes, pen matings among half sib or more closely related animals are avoided.

The combination of the repeat mating system in each selected strain, plus the random bred control strains, permits accurate separation of genetic change from environmental trends in performance from one lambing to another. This is essential in long term genetics research, where feeding and management of the flock does not remain constant but continually evolves as new information becomes available.

Table 1. Numbers of sires and dams in the selected and control sheep populations[a]

Code	Strain	Principal selection criteria[b]	Number of rams	Number of ewes
ARC Strain 1	Synthetic sire strain	Lean growth	50	400
ARC Strain 2	Synthetic dam strain	Litter size	50	400
ARC Strain 3	Synthetic dam strain	Litter size	50	400
	Sub Total		150	1200
ARC Strain 4	Suffolk control strain	None	40	80
ARC Strain 5	Finnish Landrace control strain	None	40	80
ARC Strain 6	Strain 3 control strain	None	40	80
	Sub Total		120	240
	TOTAL		270	1440

[a]Each strain is divided into two equal flocks which are mated alternately every 4 months to provide an 8 month breeding cycle (see Figure 9, page 27).

[b]Selection in the synthetic strains was initiated in 1971 and continued until 1977. Subsequently, random mating within the strains was carried out until 1980. After establishment of the hysterectomy derived flock in 1981, selection was again initiated and is continuing.

2.1.4 Selection

Selection in the synthetic sire strain is based primarily on weights of lambs surviving to 91 days of age (70 days before 1981). There is a high correlation between body weights at 70 days and the more usual 140 days of age (27). This permits the early selection of replacement breeding stock, which is essential to maintain the 8 month lambing interval in the accelerated lambing program. To improve the accuracy of the genetic assessment, records are adjusted for sex and litter size. From 1984, information on the growth of half and full sibs was used in addition to individual performance in the selection index. Moderate levels of heritability estimates (0.25), for lamb weights under a controlled environment with artificial rearing (167), suggested that family selection should effectively improve the growth performance of ARC Strain 1, making it an alternative to existing meat-type sire breeds.

Selection in the synthetic dam strains is based primarily on litter size, with lesser emphasis on growth rate (heavier lambs within a litter are usually selected). The influence of age of dam on litter size is important, therefore appropriate adjustments are made to the individual records. The heritability of litter size is small but, as the number of records increases, heritability based on the average of these records increases. From 1984, the selection index for litter size was based on the lifetime performance of the dam and granddams (paternal and maternal).

Culling of mature ewes is based on their ability to produce lambs at 8 month intervals. Usually any ewe which fails to lamb is culled. However, ewe lambs exposed to rams at 6.5-7.5 months of age are given a second chance. There has been no selection directed at wool characteristics or yield. Lambs having severe physical abnormalities, e.g. cryptorchids, crooked legs due to joint or bone malformation, severe parrot jaw, horns or colored fleece (rams only), are culled. Indirect selection for adaptability to intensive conditions includes response to artificial photoperiods, hormonal treatments to induce and synchronize estrus, sustained lamb production at 8 month intervals, controlled environment and, in ewes, early maturity and fertility.

2.1.5 Performance Characteristics of the Selected and Control Strains

Performance characteristics for the selected and control strains are summarized in Table 2. It should be emphasized that these figures represent average values from the time the flock was re-established by hysterectomy in 1980. To date, it has not been possible to carry out detailed analyses to assess the response to selection.

It can be concluded from these data that the performance characteristics of the synthetic sire strain (Strain 1) are comparable to those of the Suffolk control (Strain 4), whereas, the synthetic dam strains (Strains 2 & 3) are comparable in reproductive performance and superior in growth performance to the Finnish Landrace control (Strain 5). It should also be emphasized that the average litter size of the dam strains is superior to any contemporary domestic breed.

Table 2. Selected performance characteristics of the ARC synthetic strains and comparison with Suffolk (Strain 4) and Finnish Landrace (Strain 5) control strains

Performance characteristic	ARC synthetic strains			Control strains	
	Strain 1	Strain 2	Strain 3	Strain 4	Strain 5
Adult body wt (kg)					
Ram	94	94	96	89	86
Ewe	89	82	85	79	66
Fertility (%)					
Adult ewe	70	80	82	73	84
Ewe lamb	37	55	57	28	72
Average litter size					
Adult ewe	1.9	2.6	2.5	1.7	2.9
Ewe lamb	1.3	1.8	1.7	1.0	1.9
Body wt of lambs (kg)					
At birth	4.6	3.4	3.6	4.6	2.4
At weaning (21 days)	11.5	9.5	9.8	10.6	7.4
At end of test (91 days)	31.5	28.6	29.5	29.6	22.6
Carcass characteristics of ram lambs at 117-120 days of age					
Hot carcass wt (kg)	37	34	34	36	28
Loin eye area (sq cm)	13.4	11.6	11.7	14.1	9.6
Backfat depth (mm)	6.6	5.8	5.3	5.9	4.4
Lean muscle (% of cold carcass wt)	44	43	43	44	43

2.1.6 Related Research

2.1.6.1 Growth of crossbred lambs. A comparison of the growth of lambs sired by rams of the imported breeds with that of lambs sired by the Suffolk (113) showed no significant effects of breed of sire on the weight of single cross and backcross lambs at weaning (56 days), 100 and 140 days of age. Lambs sired by Finnish Landrace and East Friesian rams weighed less at birth than those sired by Suffolk and Ile de France rams. This study showed that the Finnsheep with high prolificacy and with lamb weights comparable to Suffolk sired crossbreds were suitable for inclusion into the synthetic dam strains. Backcross lambs from East Friesian sires appeared to have merit for lamb production. However, crossbred progeny of Ile de France rams did not appear to have any superiority in growth performance over Suffolk sired progeny. Nevertheless, including the Ile de France in ARC Strain 1 has diversified the gene pool by increasing the genetic variation available for selection.

2.1.6.2 Growth of lambs reared artificially or with their dams. A series of studies established that genetic response to selection for lamb weight can be increased if the lambs are reared artificially, independent of maternal effects (27,28,129,167). Heterosis (the superiority of crossbreds over purebreds) for growth was significant both from weaning to 70 days, and from 70-140 days of age, for lambs reared artificially but only in the latter period for lambs reared with their dams. The lower heterosis from weaning to 70 days, by lambs reared with their dams, was apparently the result of the carryover effect of restricted milk intake, which limited the expression of breed of sire differences. Heritability estimates for weights of lambs reared artificially tended to be larger than corresponding estimates for lambs reared with their dams. The results indicated selection for lamb weights will result in superior growth regardless of whether the lambs were raised artificially or with their dams. However, lambs reared with their dams should be tested for postweaning performance to permit full expression of transmitted sire differences.

2.1.6.3 Factors affecting testicular and body measurements in ram lambs. Studies carried out on growing rams of the synthetic and control strains demonstrated the importance of breed, birth date, age of ram and body weight on testicular and body measurements and the requirement for appropriate adjustments to be made, if such measurements are to be used as indicators of fertility related traits (128,151). While the usefulness of such measurements as an aid in selection is limited, they provide a reference for body size and conformation characteristics of the synthetic and control strains maintained in a controlled environment under good feeding and management conditions.

2.1.6.4 Prediction of carcass composition. The development of accurate methods for predicting carcass composition in live animals is important for large scale selection programs. Among the objective methods suitable for use on live animals, ultrasonic techniques appear to be the most promising, having been used extensively in the pig industry. However, a detailed evaluation of different instruments[1] showed that the ultrasonic prediction of carcass lean

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[1]Krautkramer USM #2®, Canadian N.D.E. Technology Ltd., Rexdale, Ont.: Scanoprobe Model 731A® and Scanogram Model 722®, Scanco Inc., Ithaca, NY.

in ram lambs, which ranged from 16-51 kg live weight, lacked the precision necessary for practical application (63,135). Heritability estimates for the carcass traits assessed ranged from 0.38-0.67 in the synthetic strains. Genetic and phenotypic parameters estimated at a fixed weight and age showed a significantly favorable relationship among carcass traits such as shoulder, leg, trimmed retail cuts, total lean and lean per day, indicating their usefulness as selection criteria for improvement of lean growth (175).

2.2 NUTRITION RESEARCH

Nutrition research has focused on nutritional requirements and on the development of effective and economical feeding and management practices for all phases of intensive sheep production in a controlled environment. A major achievement has been the development of an effective artificial lamb rearing system (Appendix D). Substantial savings in milk replacer costs have been realized by reducing the weaning age from 35 to 21 days. Lower cost lamb milk replacer formulations have been developed and satisfactory, cheaper alternatives to specially formulated milk replacer have been identified. Postweaning diets allow lambs to achieve their maximum growth potential. Practical feeding programs, based on conserved forage, have also been developed to meet the nutritional requirements of ewes under an accelerated lamb production system.

Basic research is being carried out on ruminant digestion and trace minerals using the sheep as a model ruminant. Those aspects concerned with the availability of nutrients and the reduction of nutritional disorders associated with trace mineral deficiencies, toxicities or imbalances also relate directly to improving the efficiency of sheep production. Specialized techniques and equipment were developed for carrying out these studies (Appendix E).

2.2.1 Artificial Rearing of Lambs

Before 1971, in accordance with available recommendations, lambs were weaned from milk replacer at 35 days of age. One of the first successful innovations was to reduce the weaning age from 35 to 21 days and to wean the lambs abruptly from milk replacer. Under the ARC artificial rearing system intake of milk replacer could not be reduced gradually, as was recommended, because each pen contained several lambs per available nipple. The lower weaning age reduced the milk replacer requirements from 18 to 8 kg dry powder per lamb, a major saving of this high cost feed (about $1.80/kg at present).

Lambs weaned abruptly at 21 days suffer a temporary growth check, typically losing weight or failing to gain weight during the first week postweaning (Figure 4). Thereafter, normal gains are resumed. Up to weaning, creep feed consumption per lamb amounts to about 250 g. It is unlikely the rumen has become fully functional at weaning, which probably contributes to the initial setback. Nevertheless, microbiological studies showed rumen fauna was well developed by 21 days. Rumen pH and volatile fatty acid profiles indicated rumen function reached adult status by 2 weeks postweaning (32). These findings, together with the rapid recovery from the postweaning setback, indicated that the rumen rapidly became fully functional when stimulated to do so by withdrawal of milk replacer, provided that some solid food had been consumed.

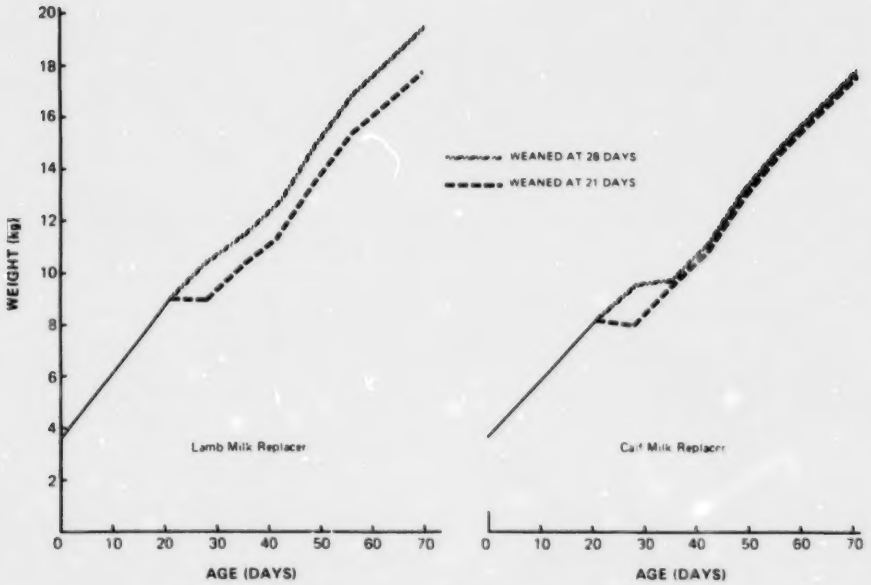

Figure 4. Growth curves of lambs weaned at 21 or 28 days of age. (From Ref. 137).

Although feeding milk replacer beyond 21 days will minimize the setback in growth, it is not economical to do so (137). Delay of weaning to 28 days for lambs fed lamb milk replacer essentially eliminated the growth check. In those fed high quality calf milk replacer the setback in growth was only reduced (Figure 4). In lambs fed lamb milk replacer, the delay in weaning resulted in an extra 1.6 kg liveweight per lamb at 70 days. This extra gain was not sufficient to cover the cost of the additional milk replacer (2.9 kg) required. At present prices the extra milk replacer would cost over $5.00. A decrease in the cost of milk replacer and/or increase in lamb prices sufficient to change the picture is not likely in the foreseeable future.

Experiments have shown that the fat level in dry milk replacer can be reduced to 24% from the 30% usually contained in commercial products without affecting lamb performance (101). The reduction in fat level can result in savings of up to 10%, primarily because easier homogenization reduces manufacturing costs. Replacement of coconut oil (50% of the total fat in the milk replacer formulation) by low erucic acid rapeseed (Canola) oil resulted in unsatisfactory lamb performance (103). Average daily gains were depressed by 18% (227 vs 186 g) and subjective observations indicated that lambs fed the coconut oil milk replacer had firmer feces with less odor and were more thrifty than those fed milk replacer containing Canola oil.

Other results indicated that satisfactory lamb performance could be achieved with high quality calf milk replacer or whole cow's milk (102). Weaning weights of lambs fed calf milk replacer or cow's milk were 5-10% lower and lamb mortality was increased 2-5% compared with those fed lamb milk replacer. However, these products could be economical alternatives to specially formulated lamb milk replacers because the lower cost would offset the slight reduction in lamb performance.

A recent study showed that lambs performed equally well when raised on milk replacer in which all the protein was provided by spray dried milk products or on a formulation in which 33% of the milk protein was replaced by soyflour (172). Although postweaning gains were marginally lower among lambs from larger litters fed the soyflour milk replacer, the results indicated it may be economical to replace at least part of the high cost milk products in lamb milk replacer with lower cost protein sources.

Losses caused by abomasal bloat were reduced from 16% to less than 2% by placing ice packs in the milk containers (27). Since 1970, abomasal bloat has been eliminated by feeding refrigerated (4°C) milk replacer from the pipelines. Recently, the feeding of warm milk replacer was re-evaluated in experiments in which lambs were fed reconstituted milk replacer with 1 ml formalin added per kg (approx. 0.1% v/w) at 4°C or at room temperature (approx 20°C) (159). No cases of abomasal bloat or other digestive disturbances were detected and lamb survival was the same at both milk replacer temperatures. The lambs fed warm milk replacer consumed more and were heavier at weaning than those fed cold milk replacer. These results indicated that feeding warm milk replacer containing formalin allows the use of simpler and less expensive equipment by eliminating the cost of refrigeration. It also allows the reduced labor costs associated with ad libitum feeding to be safely realized. On the other hand, feeding warm milk replacer required approximately 1.2-1.4 kg more milk replacer dry powder per lamb weaned. The cost of additional milk replacer might be offset by the increase in weight at weaning. However, this may not always happen because compensatory postweaning growth may eliminate the cost advantage.

2.2.2 Nutrition of Early Weaned Lambs

Under intensive management systems it is desirable to feed high energy postweaning diets to maximize daily gains, reduce costs and shorten the time required for the lambs to reach market weight. Postweaning nutrition research has investigated the dietary requirements of lambs weaned abruptly from milk replacer, at a very early age, on to high energy growing and finishing diets.

Maximum postweaning growth performance of lambs has been achieved by diets containing 20% protein, on an as fed basis, from weaning to 56 days of age, and 17% protein from 57-140 days (121). However, reducing dietary protein from 20% to 17% from weaning to 56 days of age and from 17% to 14% from 99-140 days resulted in only a slight reduction in weight gain and would be more economical. This study also showed that lambs weaned at 21 days of age can adapt to and use urea, but its use should be delayed until at least 2 weeks after weaning to ensure development of a fully functional rumen.

Other studies showed that a postweaning dietary calcium to phosphorus ratio of 2.9:1 provided satisfactory growth when the lambs were fed diets containing vitamin D at 10-20% above recommended levels (158). The results did not support the practice of supplementing lambs housed indoors with high levels of vitamin D by injection. Indeed, they showed that such treatment can have an adverse effect on growth when the calcium to phosphorus ratio is less than 1:1. Moreover, although serum calcium and phosphorus levels tended to reflect dietary intake of these minerals, they were of little value as indicators of nutritional status.

2.2.3 Adult Ewe Nutrition

A series of experiments (7,25,26,33,36) showed that the feed requirements for pregnancy during the first 14-15 weeks after mating were no greater than for maintenance. The data indicated that pregnancy itself, as distinct from fetal growth, reduced rather than increased the energy requirement of the ewe early in gestation, prior to the stage of rapid fetal growth. During the last 5-6 weeks of gestation, feed requirements increased by about 12% in ewes carrying singles and by about 25% in those carrying twins. Limited data suggested a similar linear increase in ewes carrying triplets.

2.2.4 Ruminant Digestion and Trace Mineral Research

The minimal disease sheep flock established by hysterectomy lacks ciliate protozoa in the rumen and has remained fauna free. In normal adult ruminants ciliate protozoa make up as much as 50% of the rumen microbial biomass. While it has been known for some time that protozoa are not required for survival of the host there is little information on the role played by protozoa in digestion of feedstuffs and nutrient availability. The fauna free sheep have provided a unique opportunity to investigate the functional role of protozoa in the rumen. Studies have shown that the lack of protozoa increases the efficiency with which dietary protein is utilized while decreasing the apparent digestion of organic matter, cellulose and starch (130,152). Although the effects of these findings on sheep productivity, i.e. growth, milk production, feed intake and utilization, are not well defined, it is likely that differences in nutrient utilization, in the absence of protozoa, would influence dietary protein requirements and the nature of the diet needed for optimum performance (level and type of protein, level of readily fermentable carbohydrate).

Chronic copper toxicity resulting in high mortality was diagnosed in the ARC research flock when the hysterectomized lambs were 10-12 months old. The outbreak occurred without any change in the dietary regimen and was cured by supplements of ammonium molybdate and sodium sulfate (140). Subsequent studies (173) showed that in the absence of rumen protozoa, with diets containing soluble protein, liver copper accumulated to levels which were usually associated with chronic copper toxicity, even at dietary copper levels normally considered safe. The differences in liver copper accumulation by faunated and fauna free sheep were probably due to rumen protozoa causing increases in the breakdown of dietary proteins (152). Thus increased protein breakdown in faunated sheep could result in an increase of rumen sulfur, which interacts with copper to make it insoluble and, therefore, unavailable for absorption (87). These results indicated that the presence of protozoa in the rumen can play a significant role in preventing copper toxicity.

In sheep, diets high in molybdenum can cause molybdenum toxicity or, because of its interaction with copper, a copper deficiency. Both are serious production problems because they result in growth retardation, health problems and mortality. In practice, copper sulfate is widely used as a supplement to alleviate either molybdenum toxicity or copper deficiency. However, studies have shown that, although copper sulfate will eliminate molybdenum toxicity, it should not be used as a supplement in copper deficient diets because it enhances the complex interaction among copper, molybdenum and sulfur in the rumen which reduces copper solubility and utilization (163). In such situations other forms of copper, such as cupric chloride, would be more appropriate as a supplement.

2.3 REPRODUCTIVE PHYSIOLOGY RESEARCH

A comprehensive research program has been established to develop reproductive and management strategies which will improve the biological and economical efficiency of ewes and rams. Emphasis has been placed on evaluating various hormones and delivery systems to control and manipulate the estrous cycle, the manipulation of photoperiod to overcome seasonal variations in fertility, pregnancy diagnosis, artificial insemination (AI), preservation and long term storage of ram semen and spermatozoa transport in the female reproductive tract.

The research has led to the development of procedures for the use of progestagen impregnated intravaginal sponges for controlled reproduction (Appendix A), collection, processing and insemination of ram semen (Appendix B) ultrasonic detectors for pregnancy diagnosis (Appendix C) and the use of artificial photoperiods to remove seasonal restrictions on breeding. The integration of this technology with a production system based on an 8 month lambing interval has demonstrated the potential for substantial increases in lamb production.

2.3.1 Manipulation and Control of the Estrous Cycle

2.3.1.1 Use of photoperiod. Research has established that exposing ewes to alternating 4 month cycles of 18h light daily and 10h light daily could effectively reduce seasonal variations in fertility, if the ewes were synchronized and mated at the end of the short daylength cycle (96,98,100). As a result, an alternating cycle of 4 months long daylength followed by 4 months short daylength was incorporated into the ARC experimental lamb production system (see Figure 9, page 27).

2.3.1.2 Alternative treatments for control of the estrous cycle. The intravaginal sponge (Figure 5) impregnated with fluorogestone acetate (FGA) plus pregnant mares serum gonadotropin (PMSG) has a proven record for control of the estrous cycle of sheep under a variety of conditions (Appendix A). This system is used routinely in the research flock for synchronization of estrus.

Alternative drugs and delivery systems (an intravaginal sponge impregnated with medroxyprogesterone acetate (MAP)[1], subcutaneous ear implants containing

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[1]See Appendix A, page 46.

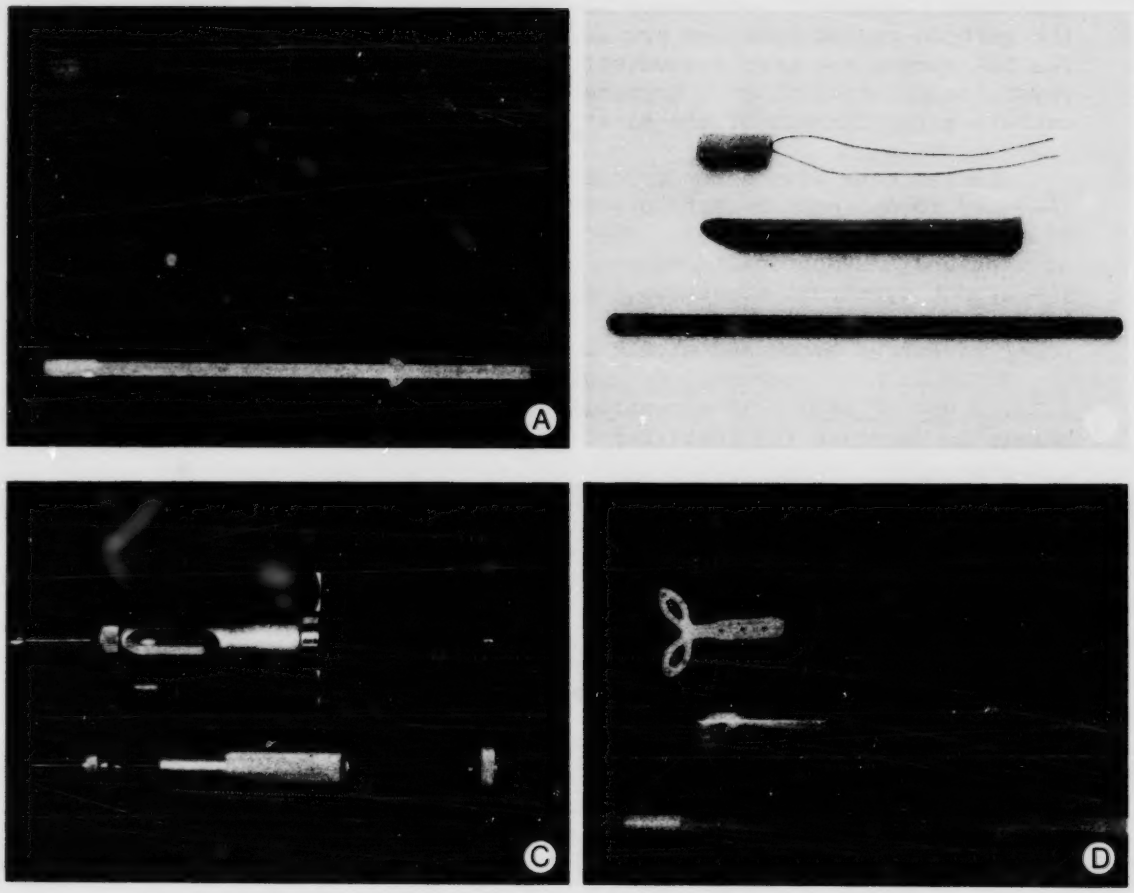

Figure 5. Alternative treatments and drug delivery systems for synchronizing the estrous cycle of ewes. (A) Intravaginal sponge impregnated with FGA for ewe lambs (upper) and adult ewes (lower) and applicator for insertion; (B) intravaginal sponge impregnated with MAP and applicator for insertion; (C) implants containing Norgestomet impregnated in a silastic polymer (upper) or polymethacrylate polymer (lower) and applicators for insertion subcutaneously in the ear; (D) intravaginal CIDR dispenser containing progesterone and applicator for insertion.

Norgestomet[1] and a controlled internal drug release (CIDR)[2] dispenser containing progesterone) have also been evaluated (93,117,118,131,153) in an effort to provide even more effective treatments and/or reduce the cost of the package (Figure 5). Comparisons of the reproductive performance of ewes after the various synchronizing treatments (Table 3) with that after FGA-sponge treatment showed that fertility and mean litter size were similar. Although the methods tested appeared promising for control of the estrous cycle, only the FGA-sponge has been evaluated under a wide range of environmental and physiological conditions. Comparable data need to be accumulated before the overall effectiveness of the alternative treatments can be assessed.

Studies have also demonstrated the effectiveness of prostaglandin-$F_{2\alpha}$ ($PGF_{2\alpha}$)[3] to synchronize estrus provided the treatment is applied to ewes that are cycling (64,79,96). The reproductive performance of ewes mated at a prostaglandin synchronized estrus was comparable to that of ewes mated at a FGA-sponge synchronized estrus. However, it was difficult to determine the best time for AI following prostaglandin treatment because of variability in onset of estrus among and within breeds or strains (77).

2.3.1.3 Use of PMSG. In a controlled environment, treatment with PMSG does not appear to increase the fertility of synchronized ewes (95,99), indicating that the main effect of PMSG is to reduce the variability in the timing of estrus and ovulation. However, it has been shown that the average litter size of ewes which lamb to mating at a synchronized estrus is increased by about 0.2 lambs when 500 IU PMSG is administered at the time of sponge removal (42,80,95,96,99).

A study on the effect of PMSG dosage (250 or 500 IU) on the reproductive performance of ewes mated at a FGA-sponge/PMSG synchronized estrus (155) showed that there was no effect of PMSG dosage on fertility or prolificacy of adult ewes. Reproductive performance of ewe lambs was lower than that of adult ewes and there was a strain X treatment interaction, suggesting a greater variability in response. These results were consistent with those of other studies (93,136) and indicated no advantage to using the higher dose of PMSG in ewes with a natural high litter size.

2.3.1.4 Application of controlled reproduction in commercial flocks. Treatment of ewes during the normal breeding season with two injections of 15 mg $PGF_{2\alpha}$ 11 days apart or 40 mg FGA-sponges for 12 days showed that both treatments were effective in synchronizing estrus (78). Estrous response over a 6 day period after treatment was 84% and 89% for the $PGF_{2\alpha}$ and FGA-sponge treatments, respectively. Ewes treated with FGA-sponges had a fertility of

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[1]Synchromate-B®, Ceva Laboratories Inc., Overland Park, KS.

[2]AHI Plastic Moulding Company, Auckland, New Zealand.

[3]Lutalyse®, Tuco Products Company, Division of Upjohn, Orangeville, Ont.

Table 3. Comparison of lambing rates after various synchronizing treatments with those after FGA-sponge/PMSG treatment

Comparison	1		2		3	
	MAP-sponge[a]	FGA-sponge	Norgestomet implant[b]	FGA-sponge	Progesterone CIDR dispenser[c]	FGA-sponge
Ewes treated	304	314	295	174	192	194
Fertility (%)						
Synchronized estrus	57	53	71	66	69	64
Overall[d]	75	72	83	85	84	84
Mean litter size						
Synchronized estrus	2.1	2.3	2.3	2.5	2.3	2.6
Overall[d]	2.0	2.1	2.2	2.3	2.3	2.4

[a]Adapted from Ref. 118.

[b]Adapted from Ref. 93.

[c]Ainsworth and Downey (unpublished observations).

[d]Synchronized plus follow-up estrus.

78% and a mean litter size of 1.3 after mating at the synchronized estrus. The corresponding values for ewes treated with $PGF_{2\alpha}$ were 63% and 1.3.

In Newfoundland, field trials carried out over 3 years with commercial flocks showed that acceptable reproductive performance can be achieved after treatment with FGA-sponges and PMSG (111). Overall fertility was 76% from matings at the synchronized estrus and 94% to matings at the synchronized plus subsequent estruses during the normal breeding season. In the spring the corresponding values were 51% and 63%. Significant variations among flocks were also found. Fertility and fecundity after mating at the synchronized estrus were 79 and 145%, 51 and 94% and 65 and 113% for Polled Dorset, Suffolk and North Country Cheviot breeds, respectively (126). These results indicated that the reproductive performance of ewes treated with FGA-sponges and PMSG during the breeding season was influenced by breed.

In a larger study in Ontario loss of sponges during treatment was low (1-2%) and approximately 95% of the ewes were mated within 72h after sponge removal, indicating a high level of synchronization. Fertility and litter size indicated that the FGA-sponge/PMSG treatment can be used successfully under commercial flock conditions (Table 4). The fertility of ewes mated at the synchronized estrus was satisfactory during both the breeding season and anestrus. The decrease in overall fertility between ewes treated during the breeding season and anestrus was due largely to differences in the proportion that continued to cycle and were mated at the subsequent estrus.

The results from individual producers indicated that the estrous response to the FGA-sponge/PMSG treatment was high, regardless of the breeds used. However, choice of breed appeared to be important for acceptable overall fertility after treatment during seasonal anestrus. Finnish Landrace, Dorset and crossbreds including these breeds had a higher fertility than did Suffolks. Adequate preparation and use of proven rams increased the overall fertility, particularly the proportion of ewes which lambed to mating at the synchronized estrus. The lambing patterns were very consistant. Ewes lambed over two distinct 4-6 day periods, depending on whether they conceived to breeding at the synchronized or subsequent estrus.

2.3.2 Pregnancy Diagnosis

Considerable experience at ARC with portable ultrasonic pregnancy detectors has demonstrated that such instruments allow rapid, simple and accurate testing for pregnancy without special facilities or training (148). A routine procedure for ultrasonic pregnancy testing of synchronized ewes has been developed (Appendix C).

2.3.3 Artificial Insemination

2.3.3.1 Fresh semen studies. Most studies have been directed towards defining the conditions for AI to breed synchronized ewes. To achieve fertility (65-75%) comparable to that obtained by natural service at a synchronized estrus, ewes should be inseminated 55h after removal of FGA-sponges (see Figure 24, page 60) with at least 200 million spermatozoa (107,108) (Figure 6). Treatment with PMSG at sponge removal is also necessary (71,106,124). A study showed that extended semen could be stored at 4°C for up to 24h without a

Table 4. Lambing outcome in response to treatment with FGA-sponges and PMSG at different times of the year in commercial sheep flocks[a]

Treatment period	Flocks	Ewes treated	Synchronized estrus		Overall[b]	
			Ewes lambing %	Litter size	Ewes lambing %	Litter size
1979 Aug-Dec	9	402	61	1.71	79	1.67
1980 Aug-Dec	14	697	67	1.79	86	1.71
1981 Aug-Dec	10	497	64	1.81	82	1.75
1982 Aug-Dec	11	437	79	1.87	89	1.81
TOTAL	44	2033	68	1.80	85	1.74
1980 Mar-June	3	129	62	2.06	64	2.04
1981 Mar-June	5	334	63	1.96	71	1.89
1982 Mar-June	8	373	55	1.65	65	1.63
TOTAL	16	836	59	1.85	67	1.80

[a]PMSG dosage was 500 IU.

[b]Synchronized plus subsequent estruses.

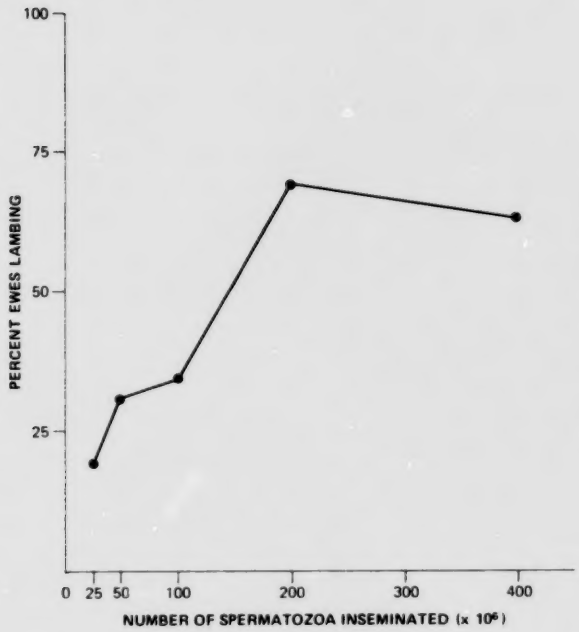

Figure 6. Effect of number of spermatozoa inseminated on fertility. (From Ref. 108).

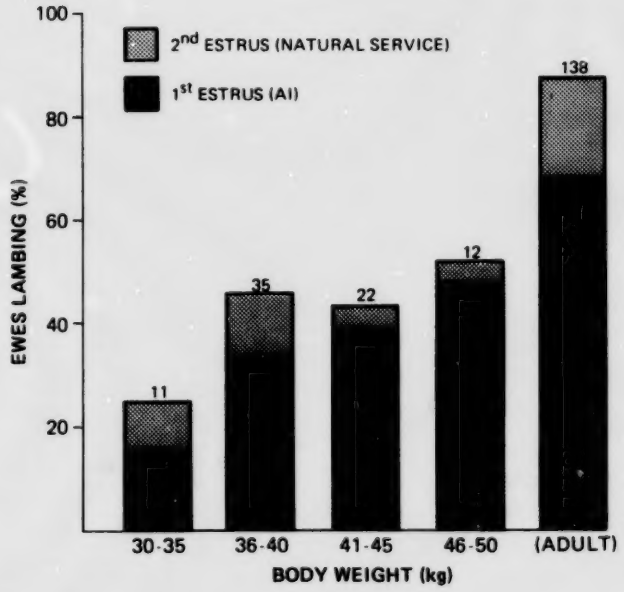

Figure 7. Influence of body weight on fertility of ewe lambs. (From Ref. 174).

reduction in fertility, whereas at 15°C fertility began to decrease when the semen was stored over 12h (70).

When using fresh semen for breeding ewe lambs by AI at a synchronized estrus (174) the fertility was about half that of adult ewes. Early embryonic mortality in ewe lambs was estimated at 24% compared to 9% for adult ewes, which undoubtedly contributed to the reduction in fertility. Moreover, the body weight of ewe lambs at breeding had an important influence on reproductive performance. Heavier ewe lambs at breeding had higher fertility (Figure 7) and larger litter size.

2.3.3.2 Frozen semen studies. The studies summarized in the preceding section showed that the reproductive performance of ewes bred by AI with fresh semen was comparable to that obtained by natural mating. It is evident, however, that the full benefits of AI will be realized only when frozen semen can be used successfully in commercial practice. It is generally agreed that the main reasons for unsatisfactory fertility with frozen semen are reduced fertilizing capability of the spermatozoa plus impairment of spermatozoa transport and losses of spermatozoa in the cervix. The net effect is a reduction in the number of viable spermatozoa reaching the site of fertilization.

Initial studies (57) showed that lambing rates after AI with frozen/thawed semen were about one half those achieved with fresh semen. Embryonic mortality, estimated during the first 2 weeks of pregnancy, was 33% for ewes receiving frozen semen compared to 6% for those receiving fresh semen. Early attempts to improve the fertility of frozen/thawed semen by altering the timing of insemination, supplementing frozen semen with prostaglandins, increasing the number of spermatozoa inseminated or estradiol-17β treatment of ewes prior to insemination (72) failed to produce sufficient increases in the level of fertility to make frozen semen practical for commercial use.

More recently it has been established that semen for freezing should be collected during a decreasing daylength when freezability is high and the occurrence of abnormal spermatozoa is low (119). Comprehensive and detailed studies on the factors influencing spermatozoa survival during freezing, the composition of semen diluents, freezing and thawing rates, and their interactions (75,94,133,134,169,170) have resulted in procedures which significantly improve the survival and fertilizing capacity of frozen/thawed ram semen (Appendix B).

2.3.4 Effects of Photoperiod on Testicular Function and Semen Quality

Testicular function and semen quality were evaluated for rams exposed to artificial photoperiods of 4 months of short days (8h light daily) alternated with 1, 2 or 4 months of long days (16h light daily), or continuous short days (164,165,166). Testis size, semen quality and blood hormones (LH, FSH, prolactin and testosterone) exhibited cycles of maximum and minimum levels which corresponded to the number of months of short and long days in a repeating photoperiod. In rams exposed to continuous short days, fluctuation in testicular size and hormone levels were minimal and semen quality remained high. These studies indicate the potential for production of quality semen year round by exposing rams continuously to a short daylength.

2.3.5 Spermatozoa Transport Through the Cervix

The ability of spermatozoa to penetrate cervical mucus and retain their viability is particularly important in sheep because folds in the cervix make it impossible to put semen directly into the uterus. Semen is usually selected on the basis of spermatozoa motility even though it has not been closely correlated with fertility. The investigation of factors affecting cervical mucus penetration by spermatozoa has resulted in the development of an in vitro assay (Figure 8) based on the entry and penetration of fresh ram spermatozoa into frozen/thawed bovine cervical mucus (147). The procedure measures the distance travelled by the leading spermatozoa in 20 min, defined as the spermatozoa penetration distance (SPD). This procedure is useful for investigating factors influencing spermatozoa transport through cervical mucus and could provide the basis for a more objective assessment of the potential fertilizing capability of ram semen.

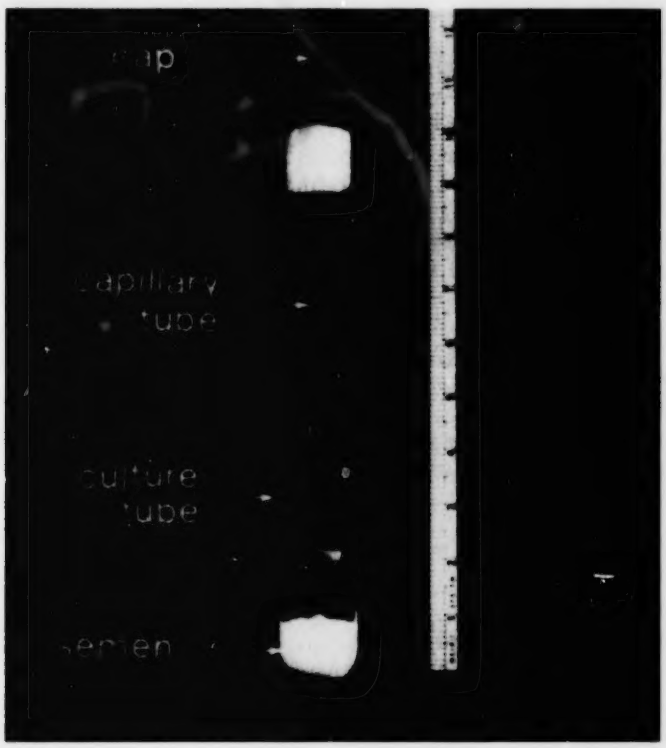

Figure 8. Assembly for studying penetration of ram spermatozoa in bovine cervical mucus. (From Ref. 147).

2.4 FUTURE RESEARCH

Selection over successive generations for lean growth rate in the synthetic sire strain and for increased lamb production in the two synthetic dam strains, plus maintenance of the unselected controls, will continue until sufficient data are collected to permit estimation of genetic trends for both direct and correlated responses to selection. Two flocks, a breeding interval of 8 months, artificial light cycles, estrous synchronization and artificial rearing, will be retained as routine management practices to increase selection pressure.

The crossbreeding phase of the selection project was initiated in October 1985 to evaluate the potential of the synthetic strains. This study will use reciprocal crosses of the synthetic dam strains. The Finnish Landrace will be used as a control for comparison with the productivity of the synthetic strain crossbreds. The latter will be mated to Suffolk and ARC Strain 1 rams to produce specific three way crosses. To estimate hybrid vigor (superiority of crossbreds over purebreds), the productivity of these crosses will be compared with ARC Strain 1 and Suffolk. Body composition, carcass and sensory traits will also be assessed. No selection will be practiced during the crossbreeding evaluation but replacement lambs will be chosen at random. Culling will be practiced only to maintain a healthy flock free of physical abnormalities. These crossbreeding studies are being carried out in a conventional environment. The ewes are be mated once a year during November, after synchronization of estrus with FGA-sponges.

Complementary studies to evaluate the production potential of ARC Strains 1 and 2 have been initiated in collaboration with the University of Manitoba. ARC Strain 2 X Suffolk crossbred ewes are used to evaluate the parental breeds based on lamb and ewe productivity. ARC Strain 1 and Hampshire rams will be evaluated as meat type terminal sires for the commercial ewes. Ewes are mated under an accelerated 8 month breeding program after synchronization of estrus with MAP-impregnated intravaginal sponges. Use of PMSG has been restricted to matings carried out during seasonal anestrus.

The ARC selected and control populations are being used to accumulate data on live animal (ultrasonic) and carcass measurements of lean meat, chemical composition and sensory evaluation of lean meat over successive generations, to permit estimation of genetic and phenotypic parameters of lean meat yield. Studies will be initiated to monitor age at puberty and ovulation rate over successive matings, after synchronization of estrus in ewe lambs and adult ewes, to assess the significance of these parameters as selection criteria for increasing reproductive performance.

Artificial rearing and feeding high energy rations to lambs to maximize growth rate represent major cost factors in intensive sheep production. Nutrition research will continue to be directed towards reducing these feed costs without compromising growth rate. If the ability to detect fetal numbers accurately during early pregnancy using real-time ultrasound proves successful, new studies to define energy and protein requirements for prolific ewes during pregnancy will be initiated.

Observations of lamb behavior associated with the suckling stimulus has led to the design and evaluation of artificial milk delivery systems better adapted to the natural sucking reflex of the lamb. These studies could lead to procedures which reduce the labor and time required to teach lambs to nurse independently when reared artificially and the incidence of suckling related behavior problems.

Reproductive physiology research will continue to emphasize the development and evaluation of improved reproductive and management strategies for increasing the output and efficiency of intensive lamb production systems. Studies have begun to evaluate the effects of various factors on the onset of puberty and fertility of ewe lambs and initiation of cyclic ovarian activity in postpartum ewes. Research on the use of photoperiod to control testicular activity, factors influencing spermatozoa transport through cervical mucus and improving procedures for long term preservation and conservation of the fertilizing capacity of ram spermatozoa will continue. Results from these studies should reduce or eliminate the seasonal constraints on breeding, allow collection of high quality semen year round and increase the efficiency of AI programs.

3. THE EXPERIMENTAL LAMB PRODUCTION SYSTEM

Since 1974, the research flock has been divided into two flocks with animals and genetic material being distributed equally. Each flock has an 8 month lambing interval. The two flocks are mated alternately in January, May and September so that lambs are produced every 4 months (Figure 9). Between matings, each flock is exposed to an artificial daily photoperiod of 16h light for 4 months followed by 9h light for 4 months. Each flock is mated at the end of its short day cycle. Overall, the research flock consists of 1440 ewes and 270 rams plus 1000-2000 lambs, depending on the time of the year.

The production system has evolved concurrently with research progress, experience and management innovations. Major emphasis has been placed on the development and application of procedures which increase productivity, reduce cost and/or increase efficiency. The system as described represents the current status, but modifications will continue to be made as new findings become available.

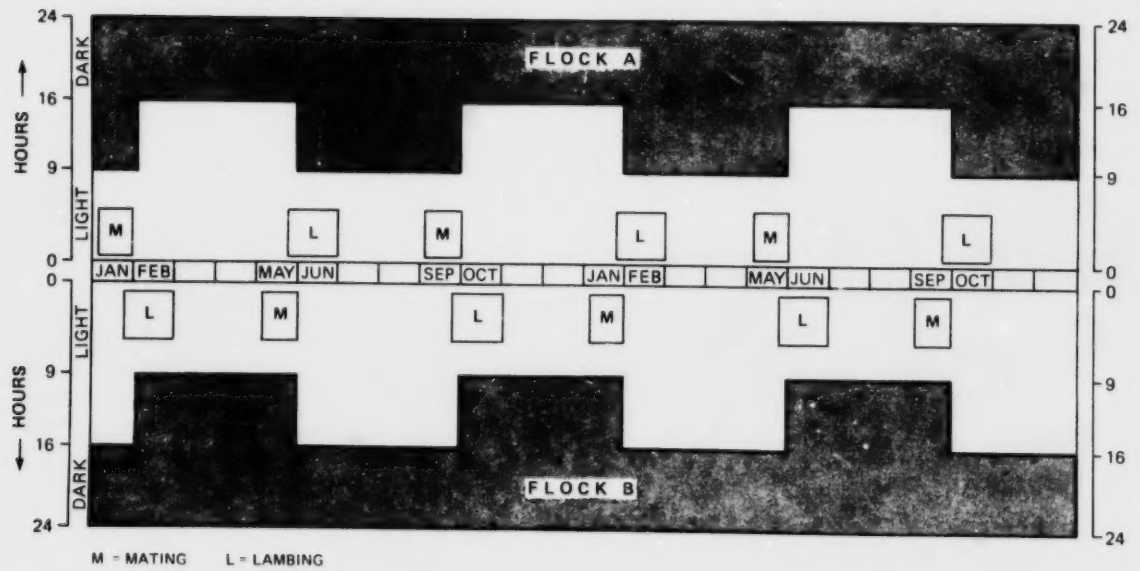

Figure 9. The two-flock accelerated lambing cycle for the experimental lamb production system. M=Mating; L=Lambing.

3.1 FACILITIES

The facilities at the ARC Research Farm allow research on a high output, intensively managed lamb production system and for associated basic studies (88). The construction techniques and materials used can be economically copied and adapted by the Canadian agricultural industry.

The experimental production flock is housed in three single story, windowless, insulated barns. The barns function as an integrated unit (Figure 10). The large adult barn (Figure 11) holds 1440 ewes and 270 rams. The liquid diet barn (Figure 12) and the growing barn (Figure 13) each hold 1600 lambs. Incandescent lighting is controlled by time clocks so that the daily light:dark cycle can be regulated. Animal areas have expanded metal mesh floors over liquid manure pits, and each animal pen is provided with an automatic water dispenser. Pen sizes are adjustable to hold varying numbers of animals. Feed is delivered by an automated system from a central feed storage area (Figure 14).

A separate barn at the Research Farm is designed for basic research (Figure 15). It contains an area of 128 pens with movable partitions so that sheep can be fed either individually or in groups as required. A second area, provides facilities for digestion and metabolism trials. A third area contains several rooms individually equipped with time clocks and thermostatically controlled heating and air conditioning so that light and temperature can be regulated. Six of these climate controlled rooms will hold up to four mature animals, and five larger rooms will hold up to 15 animals each. The barn also contains well equipped service areas to support the varied basic studies that are carried out.

Two conventional barns, one constructed of wood and the other metal, each with adjoining outside paddocks and pasture are also used for sheep research. They hold up to 400 animals and are used for production research with traditional management e.g. crossbreeding and performance evaluation of the synthetic strains (see page 25).

3.2 FLOCK MANAGEMENT

The two flocks have been reared successfully from birth in the controlled environment facilities for several generations and have not been exposed to natural daylight or pasture since 1974. The sheep have proved to be very adaptable to this type of management. Predators have been completely eliminated and there are no internal or external parasites, foot rot or sore mouth (contagious ecthyma). Thus, there is no need for dipping and dosing which reduces operating costs.

3.2.1 Breeding Flock

The feeding program for the adult sheep has consistently emphasized the use of forages. It is flexible and is modified as a result of research findings, experience or availability of harvested feedstuffs at the Research Farm's central feed storage. Currently, between breedings and during early

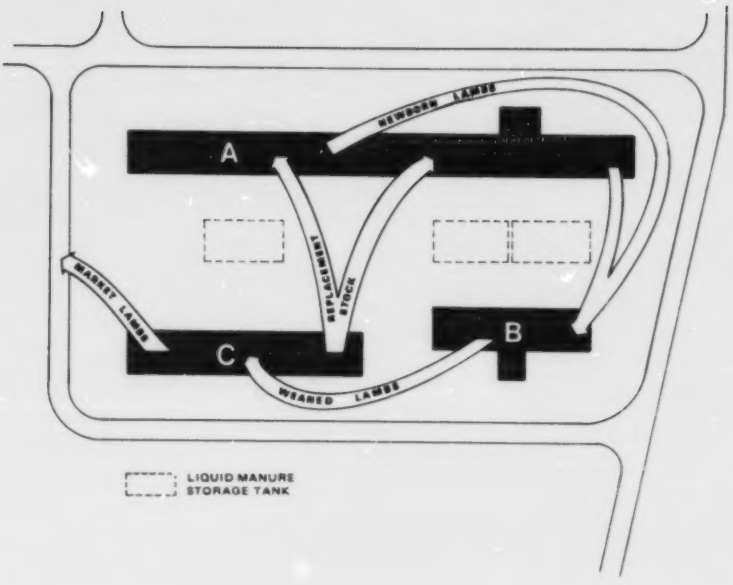

Figure 10. Schematic animal flow pattern for the experimental production flock. (A) Adult barn; (B) liquid diet barn; (C) growing barn.

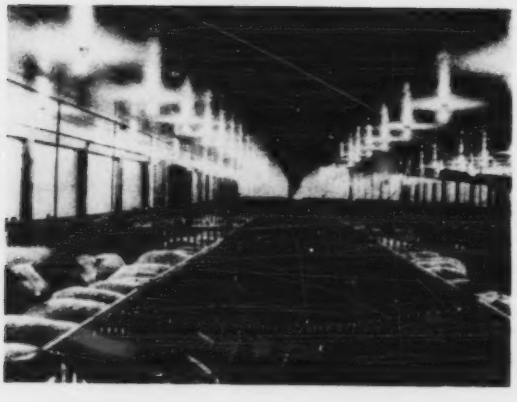

Figure 11. Representative interior view of the adult barn.

Figure 12. Pen of lambs in the liquid diet barn.

Figure 13. Representative interior view of the growing barn.

Figure 14. Feed delivery. (A) Mixer truck delivers feed to the conveyor system which (B) distributes it to the sheep.

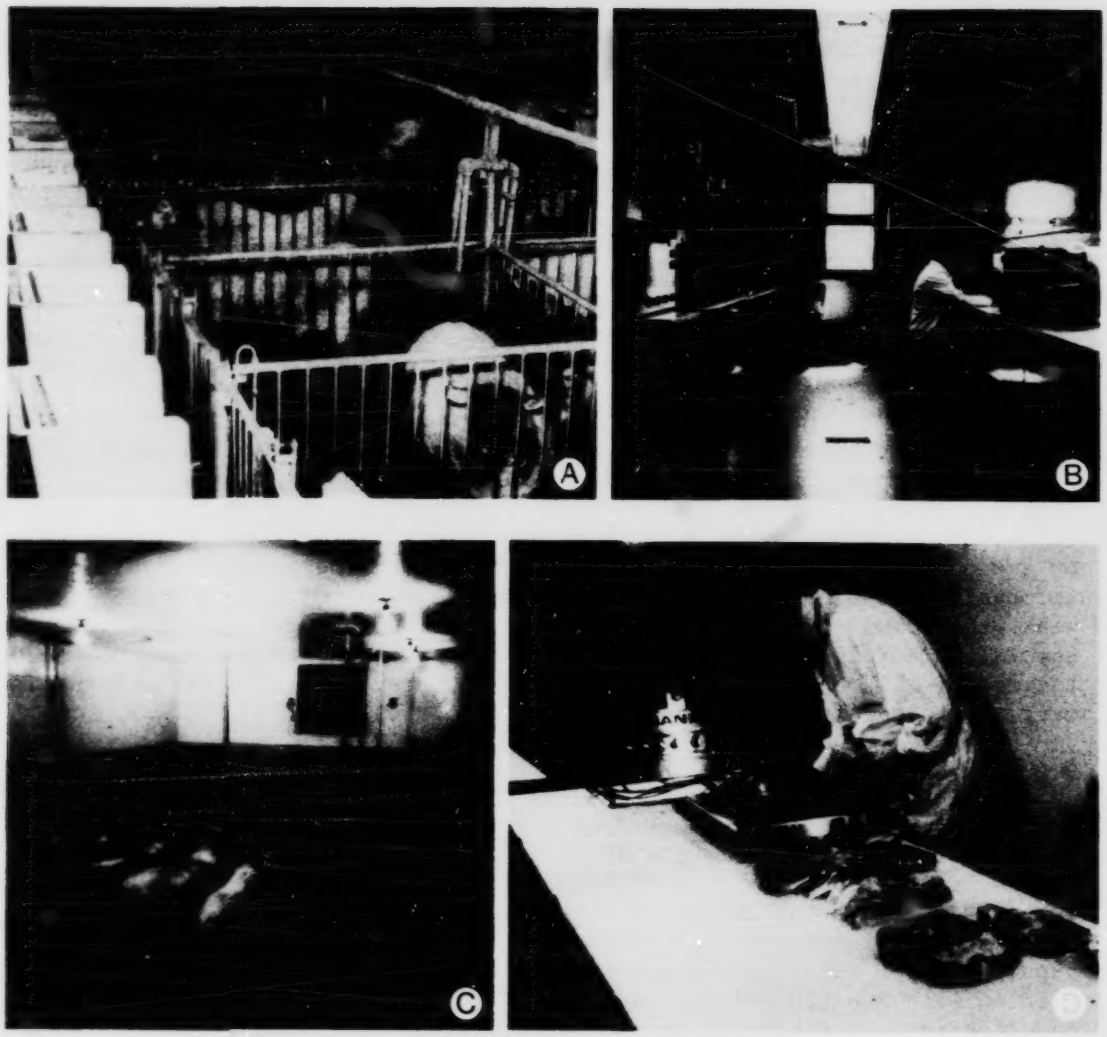

Figure 15. Representative facilities for basic research. (A) Pens for individual feeding; (B) semen processing; (C) climate controlled room; (D) carcass evaluation.

gestation the ewes are fed an essentially all-forage diet consisting of 20% hay, 75% alfalfa silage (field wilted, naturally preserved or direct cut, formic acid preserved) and 5% grain as a carrier for needed vitamins and minerals. Grain is increased to 18% for flushing and for 4-5 weeks before lambing. Depending on the condition of the ewes during pregnancy, grain may be further increased up to 30% for about 2 weeks before lambing.

Estrus and ovulation are synchronized by treatment with FGA-impregnated sponges for 14 days and intramuscular injections of 250 IU PMSG at sponge removal. Synchronized ewes are bred either by natural mating, or by artificial insemination (AI) 55h after sponge removal. Rams are introduced to the ewes within 24h after sponge removal and remain for 23 days to allow ewes which did not conceive at the synchronized estrus to be re-bred at the follow-up estrus.

Pregnancy diagnosis (Appendix C) allows ewes to be separated into pregnant and non-pregnant groups and fed separately according to their needs. Each flock is sheared 8-10 weeks before lambing.

At lambing, eartags provide a permanent pedigree record for each lamb. The date and hour of birth, strain, sex, birth weight, dam and sire of the lamb(s), lambing problems and milking problems are also recorded. As each ewe lambs, she and her lamb(s) are held in a temporary 1.2 X 1.2 m area enclosed by a wooden hurdle (Figure 16A). Lambs stay with their dams only long enough to obtain colostrum. When the dam is deficient in colostrum or the lambs are weak, the lambs are moved to a draft free, bedded brooder with heat lamps for special care (Figure 16B). Frozen cow colostrum, thawed and rewarmed to body temperature, is bottle fed to these lambs. Once or twice a day all the lambs over 6h of age are transferred to the liquid diet barn.

3.2.2 Lamb Rearing

In the liquid diet barn, the lambs are first placed in 'starter' pens where they are trained to suck from a nipple bar (Figure 17). These pens have plywood covered by 2-4 cm of shavings over about two thirds of the metal mesh floors, at the ends opposite the nipple bars. Training takes 1-2 days but the lambs stay in a 'starter' pen for at least 3 days to be sure they are well trained. The lambs are then grouped by size and moved into regular unbedded pens. After 5 days the lambs are docked, using a burdizzo and knife, and treated with 300 000 units of a long acting penicillin[1] to reduce the risk of infection. A special care area consisting of individual brooders and a recovery area is provided for problem lambs, i.e. those with health problems, physical abnormalities, are too small to reach the nipple bars, slow drinkers and "suckers".

Reconstituted lamb milk replacer, containing 24% fat and 24% protein in the dry powder (Table 5), is fed ad libitum by pipeline. In each pen 12 nipples feed up to 50 lambs. Water is available at all times and a palatable creep feed and good quality alfalfa hay are provided from birth to encourage

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[1]Pendure Neat®, Armitage Carroll Ltd., London, Ont.

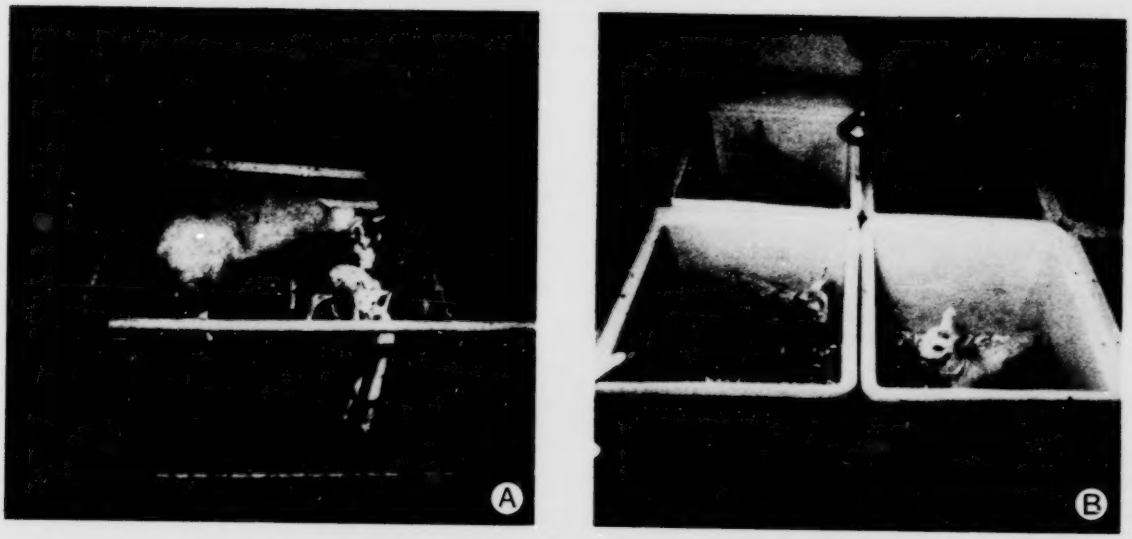

Figure 16. (A) Ewe with newborn lambs in temporary enclosure; (B) brooder for lambs needing special care.

Figure 17. (A) Training lambs to suck from a nipple bar; (B) lambs nursing from a nipple bar.

Table 5. Composition of lamb milk replacer

Ingredient	%
Skim milk	55.0
Buttermilk	19.0
Coconut oil	11.8
Tallow	10.8
Dextrose	1.4
Lecithin and emulsifier	1.3
Vitamin-mineral premix[a]	0.7

[a]Provided per kilogram of milk replacer: vitamin A 33 000 IU; vitamin D_3 5500 IU; vitamin E 25 IU; thiamine 5.5 mg; riboflavin 11 mg; niacin 11 mg; calcium pantothenate 11 mg; choline 110 mg; ascorbic acid 83 mg; vitamin B_{12} 0.016 mg; salt 2.5 g; magnesium oxide 1.25 g; calcium iodate 1.5 mg; copper (sulfate) 2.0 mg; iron (carbonate) 62.6 mg; manganese (sulfate) 65.0 mg; zinc (sulfate) 3.75 mg; cobalt (sulfate) 1.25 mg; selenium (sodium selenite) 0.3 mg.

Table 6. Growing diets fed after 91 days of age

Ingredients	Age (days)	
	91-140 %	after 140 %
Grain	70	30
Corn silage	20	--
Alfalfa silage	--	60
Chopped hay	10	10

early consumption of solid feed. At 21 days of age the lambs are weaned abruptly onto solid feed, provided they weigh a minimum of 6 kg. Smaller lambs are left on milk replacer for up to 2 more weeks to give them a better start. Average weaning weights are 10-12 kg.

After weaning, the lambs are fed ad libitum a high energy diet of approximately 90% grain, 8% hay plus vitamins and minerals and alfalfa hay free choice. The lambs are transferred from the liquid diet barn to the growing barn at 35 days of age. The postweaning diet and free choice hay are fed until end of test weights are recorded at 91 days of age. Daily gains from birth to 91 days average 275-300 g and live weights at end of test average 28-32 kg.

After 91 days the growing lambs are fed complete mixed diets with reduced energy levels to support, without excessive fattening, the rapid growth required to allow mating at 6.5-7.5 months of age (Table 6). The lambs remain in the growing barn until they are selected as breeding replacements or marketed as surplus animals. Both the liquid diet barn and growing barn are thoroughly cleaned, disinfected and fumigated between lamb crops.

In the liquid diet barn the lights are on 24h a day. In the growing barn the lambs are exposed to 16h light daily until they reach 91 days of age after which they are exposed to 9h light daily. Replacements are moved to the adult barn at 6.5-7.5 months of age. Ewe lambs are then kept on the same light schedule as the adult ewes they join in the breeding flock. Ram lambs are exposed to 16h light daily for approximately 1 month after transfer to the breeding flock. Subsequently they are exposed to 9h light daily for 7-8 months. Rams are used for breeding twice, at 10.5-11.5 months of age and again 4 months later.

3.3 PRODUCTIVITY OF THE EXPERIMENTAL PRODUCTION FLOCK

The fertility of the mature ewes in the ARC synthetic dam strains (Strains 2 & 3) is 80-85% with a litter size of 2.5-2.6. Corresponding values for the synthetic sire strain (Strain 1) are 70-75% for fertility and 1.8-2.0 for litter size. The fertility and prolificacy of the ewe lambs bred at 6.5-7.5 months of age are 50-60% of the values for the mature ewes. These figures represent an increase of approximately 15% since 1979. The average daily gains from birth to 91 days of age (275-300 g) and live weights at end of test (28-32 kg), represent an increase of over 20% since 1979. The proportion of these increases that have resulted from genetic gain versus that due to environment, particularly the minimal disease status of the flock since 1980, has not yet been analyzed.

Under the ARC lamb rearing system, the current mortality due to stillborn and neonatal deaths (prior to lambs entering the liquid diet barn) is about 10%. Lamb deaths are about 4% during artificial rearing and about 3% postweaning. These mortality figures represent an overall decrease in lamb mortality of about 5 percentage points since 1979. Most of this decrease can probably be accounted for by the minimal disease status of the flock.

On the basis of the foregoing figures the current productivity of the adult dam strains per lambing has been estimated at approximately two lambs reared per ewe bred. Because of the 8 month lambing interval the annual productivity is about three lambs reared per ewe bred. This level of productivity is probably a conservative estimate of that which could be obtained in a good commercial operation because the ARC flock is subjected to a number of constraints imposed by the research component of the program. Nevertheless, it demonstrates that the productivity of sheep can be improved substantially by intensification and the exploitation of new technology and management strategies.

3.4 FLOCK HEALTH

The staff veterinarian develops and oversees the general flock health program. Currently, the routine preventative health program consists only of vaccinations against Clostridial infections[1]. Pregnant ewes are vaccinated approximately 6 weeks prior to lambing and the lambs are given booster vaccinations at 49 and 91 days of age. No other preventative health measures are required because internal and external parasites and foot rot do not exist. Moreover, no antibiotics, sulfonanides, arsenicals or other feed additives are routinely fed to lambs. Thus, the lamb produced contains no residues from feed additives which are becoming a source of public concern in meat produced under intensive systems.

By 1978, when the adult barns had been in continuous operation for 9-10 years, a high incidence of Maedi-Visna (or chronic progressive pneumonia as it is commonly called in North America) had developed in the research flock. There had also been a gradual increase in death losses due to pneumonias and other respiratory infections. These observations were similar to those encountered in the poultry and swine industries following the shift to intensification. In 1980, the decision was taken to establish a minimal disease flock. The barns were emptied, completely cleaned and disinfected, and minor renovations were made. The barns were then repopulated with lambs derived by hysterectomy (81).

The Maedi-Visna status of the flock was monitored by serological testing of random annual samples of the hysterectomy derived ewes plus their first and second generation progeny. No positive reactors to the Maedi-Visna test were found in over 300 samples tested annually for each of 3 years, including over 200 from 5 year old ewes in the final test. In addition, pneumonias have been virtually eliminated as a cause of death. These findings indicate the hysterectomy procedure is effective in eliminating specific diseases. The minimal disease status of the flock is being protected by a partial barrier system. Everyone entering the barns is required to pass through shower facilities and wear only clothing provided by ARC inside the barns. In addition, all equipment is either sprayed with a disinfectant or fumigated before entry.

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[1]Covexin 8®, Burroughs Welcome Inc., Kirkland, Que.

3.5 COMPUTERIZED DATA HANDLING

The ARC sheep production program generates large amounts of data. Effective storage, editing and handling of such a volume of information requires a computerized system to help manage the flock and to record research data for subsequent summary and analysis. The Sheep Information Processing System (SHIPS) was initiated in 1977 (39). The system is based upon a computer 'data base management' system[1] and currently processes over 200 000 items of information annually.

Complete inventory listings of all sheep are maintained by SHIPS. Separate listings show barn and pen location for each animal. The inventories are routinely updated monthly and whenever specifically required, e.g. at breeding, lambing and marketing. Computer listings are also produced for various operations such as ewes to be mated, mating lots and rams for a given mating, ewes due to lamb and lambs to be weighed.

Data such as inventory changes, lamb weights and synchronization dates are recorded directly on to the computer listing for that operation. The recorded entries are then converted into a computer readable form, edited and entered into the SHIPS files.

Computer listings of specific sets of data, organized in any order desired (for example, by treatment), are easily retrieved using a simple System 2000 user language. Thus, preliminary summary and evaluation of data is simplified. More sophisticated programming creates specific data files for special purposes, e.g. statistical analysis, calculation of selection indexes, breed composition and generation interval.

The use of the 'data base management' system allows simple, rapid and flexible access to the large volume of stored data. Over 375 data elements are available for each sheep, covering all aspects from birth to disposal.

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[1]System 2000, MRI Systems (Canada) Ltd., Ottawa, Ont.

4. USE OF TECHNOLOGY AND MANAGEMENT STRATEGIES FOR INCREASING THE EFFICIENCY AND OUTPUT OF LAMB PRODUCTION SYSTEMS

The experimental lamb production system at ARC has demonstrated the potential for a substantial increase in output and efficiency, by intensification and the careful integration of available technology and management practices. This section discusses the technological advances and management innovations which are available to producers. The relative importance and contribution of the various components for increasing efficiency and/or output of the production system are assessed. Consideration is also given to the economics of more intensive lamb production, the requirements for effective utilization of available technology and the potential for development of productive sheep management by the Canadian sheep industry.

4.1 CONTROL OF THE ENVIRONMENT

As lamb production systems move from range operations to more intensive management, a greater proportion of the production cycle is spent in some form of housing. While increased environmental control brings with it an increase in capital requirements, it also allows for greater managerial control over available resources and more efficient production through the application of new technology and management strategies. There is little question that the sheep industry will see greater application of environmental control as it evolves to become more efficient and competitive with other animal agriculture systems.

In Canada, where sheep production can be profitable on arable land, it is already necessary to provide housing and conserved forage during the long winters. For little extra cost sheep can be housed year round. Several economic advantages help offset the associated expenses. Losses from predators, the need for costly fencing, internal and external parasites and foot rot can be eliminated. The efficiency of harvesting forage mechanically is 80-90% compared to about 60% under ideal conditions of grazing management. Moreover, the preservation and storage of harvested forages assures consistent availability of high quality year round, because the forages are harvested at the optimum times.

Labor management has not been a major concern under the traditional extensive management systems. However, by intensification and use of a controlled environment, the producer can make more efficient use of available labor, particularly at lambing, when the timely input of skilled labor is critical. Also, control of the environment allows the mechanization of at least two labor intensive operations. Feed formulation, processing and distribution can be mechanized to varying degrees as can manure handling. Although there has been little research applied directly to mechanization of manure handling for sheep, experience at the ARC Research Farm has shown that sheep manure can be handled in a liquid manure system with standard equipment. However, the manure requires more dilution than cattle manure before pumping.

Maintaining sheep in a controlled environment reduces the physical activity required to obtain feed. This directly reduces their energy requirements for maintenance. A substantial body of evidence indicates that maintenance requirements can be reduced up to 40%, or more, if the animals are maintained in a controlled environment. This is of major economic significance since feeding ewes represents the largest single cost in lamb production. Similar increases in efficiency can be obtained by feeding growing lambs in a controlled environment because environmental stresses, which adversely affect rate and efficiency of growth, are either eliminated or greatly reduced. Control of the environment also provides the opportunity to impose varying levels of control over reproduction.

4.2 CHOICE OF BREED

Frequent and high levels of reproduction and early sexual maturity are essential to the success of intensive lamb production. Only with a high output of lambs is it possible to recover the increased investment costs of such production systems. The concept of matching breed type and management resources is an important aspect of intensive sheep management systems. Utilization of prolific breeds is advantageous only if management is capable of exploiting the greater productivity.

The appropriate combination of breed resources to set specific performance objectives offers the most important potential for increasing reproductive efficiency. This involves the development of crossbreeding and/or selection programs or the use of strains or breeds developed from such programs. Also, by using the highly prolific Finnish Landrace[1] or Romanov[2] breeds in combination with domestic breeds, litter size can be increased from the current level of 1.2-1.6 lambs per ewe by 50-100% in one or two generations. Extensive evaluation of the Finnsheep in the United States has shown that 50% Finnsheep inheritance may provide the desired litter size and overall production potential for some management systems, whereas for others 25% may be more advantageous. A Finn-Dorset crossbred ewe flock has been shown to produce annually 340 lambs per 100 ewes mated under an accelerated lambing system[3]. Moreover, the contribution of other exotic breeds is equally valuable in more complex breeding programs, such as is being carried out at ARC.

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[1]Dickerson, G.E. 1977. Crossbreeding evaluation of Finnsheep and some U.S. breeds for market lamb production. North Central Regional Publ. No. 246. ARS, USDA and Univ. Nebraska, Lincoln, NE.

[2]Razungles, J.; Tchamitchian, L.; Bibe, B.; Lefevre, C.; Brunel, J.C.; Ricordeau, G. 1985. The performance of Romanov crosses and their merits as a basis for selection. Pages 39-45 in Land, R.B.; Robinson, D.W. eds., Genetics of Reproduction in Sheep. Butterworths, London, England.

[3]Robinson, J.J. 1982. Improving ewe productivity. Sheep Breeder and Sheepman 102:60-73.

4.3 FREQUENCY OF BREEDING

Increasing the frequency of breeding so that each ewe lambs more than once a year significantly increases annual lamb output, particularly if highly prolific ewes are used and high fertility can be maintained. Although a ewe's gestation period is about 5 months, it is possible for them to conceive within 6 months of their previous conception. However, there is no evidence to indicate that a continuous 6 month lambing interval can be maintained on a flock basis.

In practice, most producers aim for an 8 month breeding interval, giving three lamb crops in 2 years. With this breeding interval, the system of choice would be to split the flock into two groups and breed each group alternately at intervals of 4 months. Ewes not conceiving at one mating time would be transferred to the group being bred 4 months later. This approach, in addition to increasing the reproductive capability of the ewe, provides a practical way to increase the efficiency of the production system by:

- making more uniform use of labor;
- reducing the facilities required for lamb growing and finishing and the overhead costs per unit of production, because only half the flock lambs at a given time and the facilities are used continuously instead of sitting idle for extended periods;
- increasing the availability of lambs which provides a more uniform cash flow, since lambs can be marketed throughout the year rather than seasonally;
- spreading the lamb crop over the year lessens the chances of unusually heavy losses at one time due to disease outbreak or other adverse conditions.

4.4 BREEDING EWE LAMBS

With increasing emphasis on intensive production, there is growing interest in breeding ewe lambs to produce a lamb crop by one year of age. Comprehensive literature reviews[1] of the factors influencing sexual development and performance of ewe lambs have indicated that conception and lambing rates are lower and more variable than in adult ewes. Moreover, nutrition, breed, season of birth, age and body weight at breeding can influence the success or failure of the lambing outcome of ewe lambs. However, the effects of some of these variables can be reduced by induction and/or synchronization of the estrous cycle of ewe lambs using progestagen-impregnated intravaginal sponges and PMSG (Appendix A).

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[1]Dyrmundsson, O.R. 1981. Natural factors affecting puberty and reproductive performance in ewe lambs: A review. Livest. Prod. Sci. 8:55-65. Dyrmundsson, O.R. 1983. The influence of environmental factors on the attainment of puberty in ewe lambs. Pages 393-408 in Haresign, W. ed., Sheep Production. Butterworths, London, England.

Although the production of a lamb crop by ewe lambs from early maturing breeds at a year of age is feasible, the overall economics of breeding ewe lambs needs to be further evaluated, taking into consideration the factors which can influence the lambing outcome. This is particularly relevant to systems of intensive lamb production where correct management decisions are critical in determining the profitability of the enterprise.

4.5 CONTROL AND MANIPULATION OF REPRODUCTION IN THE EWE

4.5.1 Use of Artificial Daylength Patterns

For accelerated lambing systems in which the sheep are kept indoors at all times, it is possible to use artificial daylength patterns to control estrous cycle activity. An abrupt or gradual change from a long to a short daylength will induce cyclic activity in non-cycling animals, usually within 30-60 days after the change in daylength. Conversely, animals will stop cycling within 30-60 days if exposed to an abrupt or gradual change from a short to a long daylength. To achieve consistent results, the magnitude of the change between the short and the long daylength should be at least 6h and the periods of short/long or decreasing/increasing patterns should be applied in a rhythmic pattern. Thus, in an accelerated lambing system like that practiced at ARC (see Figure 9, page 27) ewes are mated at the end of a short daylength cycle, regardless of the time of the year they are bred. Also, since the complete production cycle is 8 months, the light changes occur at 4 month intervals.

4.5.2 Use of Exogenous Hormones

The development of the progestagen impregnated intravaginal sponge technique has provided the basis for management and control of reproduction in sheep. The application of the technique and the benefits to be gained from its use are discussed in detail in Appendix A. The use of natural and synthetic prostaglandins for control of the estrous cycle in sheep has limited application. These compounds can only be used during the breeding season when the animals are cycling. Moreover, they are only effective if administered between about days 4 and 14 of the cycle. Thus, the prostaglandin must be given in two doses 9-10 days apart to ensure that estrus is synchronized in all sheep within a flock.

4.5.3 Use of Artificial Daylength Combined With Exogenous Hormone Treatment.

One of the main problems in relying solely on artificial daylength to induce cyclic activity is its inability to synchronize the estrous cycle. This can be avoided by combining artificial daylength, which induces estrus and ovulation, with exogenous hormones to synchronize the estrous cycle (see Figure 9, page 27). The combined treatment has the advantage that animals will continue to cycle if they are not bred at the synchronized estrus, regardless of the time of the year the treatments are applied, thereby optimizing their ability to be bred and to conceive.

4.6 CONTROL AND MANIPULATION OF REPRODUCTION IN THE RAM

Management procedures are available which reduce the seasonal variations in semen quality and allow rams to be used for breeding year round

(Appendix B). Moreover, since ram fertility is important in determining the number of ewes that conceive, it is necessary to distinguish between rams of high and low fertility. This can be done by examining or measuring the testis and/or taking semen samples for analysis. Scrotal circumference is a good measure of testis size. Breeders frequently consider large size and firm tone of the testes to be good indicators of semen producing capability and fertility of rams.

4.7 ARTIFICIAL INSEMINATION

The need for AI in sheep is increasingly apparent, particularly with the move towards more intensive production systems. AI technology exploits the genetic merit of proven rams, simplifies management, increases the number of ewes that can be mated to a given ram at a synchronized estrus and reduces variations in fertility resulting from the use of rams with unknown or variable semen quality. Despite these benefits, the use of AI in Canada has been limited because of technical problems and cost. However, AI using fresh semen has become feasible, particularly when used in conjunction with controlled reproduction programs where the need to detect estrus is eliminated and the ewes can be inseminated at a predetermined time (Appendix B). Sheep inseminated with fresh semen can achieve lambing rates comparable to those obtained by natural mating at a synchronized estrus. Commercial application of AI is currently being carried out on a small scale in Ontario[1]. A ram stud has been established and procedures are being developed to achieve consistent levels of fertility when AI is used under commercial flock conditions.

Although AI with fresh semen is feasible, full realization of its potential will depend on the capability for use of frozen semen. While progress is being made, the problem of obtaining high fertility consistently with frozen semen has not yet been solved. Current research at ARC has markedly improved the survival of frozen-thawed spermatozoa through the development of new diluents and improvement of processing procedures (Appendix B). The results indicate that many of the current problems limiting the use of frozen semen technology can ultimately be resolved.

4.8 PREGNANCY DIAGNOSIS

Determination of the pregnancy status of the ewe can be economically important. Pregnant ewes can be separated and given supplemental feeding as pregnancy progresses, while open ewes can be fed cheaper diets, re-bred or culled. Over the past several years, portable ultrasonic detectors have become available which allow rapid, simple and accurate pregnancy diagnosis without special facilities or training (Appendix C).

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[1]United Breeders Inc., Guelph, Ont.

4.9 ARTIFICIAL REARING AND EARLY WEANING OF LAMBS

Artificial rearing of the entire lamb crop would not normally be recommended for commercial operations. Instead ewes should rear at least twins naturally. However, with a prolific flock many ewes will produce litters larger than two. The artificial rearing technology (Appendix D) is useful to raise the extra lambs, as well as lambs that would otherwise be orphaned by lack of milk supply, death of the dam or rejection.

There is debate about which lambs from large litters should be picked for artificial rearing. One opinion is that the larger, more vigorous lambs should be picked because small weak lambs have a better chance of survival when left with the ewe. On the other hand, the larger more vigorous lambs can take better advantage of the ewe's milking ability. Also, artificial rearing removes competition for milk supply by the small lambs. Experience at ARC has shown that small lambs can be successfully reared artificially. If the ewe is an exceptionally good milker and mother probably the best compromise would be to leave the two or three most uniform lambs with her and rear the remainder artificially.

The production of three lamb crops in two years can be accomplished with ease by weaning naturally suckled lambs at 6-8 weeks of age. The lambing interval can be reduced further by weaning at 4-5 weeks of age. However, at these ages the dams are still near the peak of lactation. Special care and management is essential to minimize mastitis and other udder problems. Under such conditions, the procedures outlined in Appendix A become especially important. In some cases it may be necessary to hand milk high producing ewes for a day or two during the drying off period. A possible exception to natural rearing would occur if the lambing interval was decreased further. This would necessitate very early rebreeding of the ewes. Under such circumstances it is known that lactation adversely affects fertility. Thus, lamb production from early rebreeding would have to offset the supplementary costs of artificial rearing.

4.10 NUTRITION AND MARKETING OF EARLY WEANED LAMBS

Under intensive management systems it is desirable to feed lambs high energy diets to maximize daily gains and feed efficiency, reduce overhead costs and shorten the time required to reach market weight. It is generally recommended that suckled lambs be provided with high quality creep feed from birth, weaned at 6-8 weeks of age when the mother's milk supply is decreasing and then fed a high energy finishing ration to market weight. Similarly, lambs reared artificially should be fed a finishing ration continuously from weaning at 3 weeks of age. The finishing rations should contain approximately 17% crude protein until the lambs are about 100 days of age and 14% thereafter until they reach desirable market weight and grade.

Creep feeding is essential for artificially reared lambs and for naturally suckled lambs weaned at less than 6 weeks of age. Although the lambs will not normally consume much creep feed before they are 2-3 weeks of age, it is

important that it is available. Intake of solid food is essential for stimulation of rumen development, which determines whether the lamb will survive as a functioning ruminant after weaning.

The marketing of intact male lambs should be encouraged to take advantage of their superior growth rate, feed efficiency and leaner carcasses. At ARC, all lambs are potential breeding replacements so none are castrated. Ram lambs surplus to breeding requirements are marketed commercially. Experience has indicated potential market discrimination is short lived provided the ram lambs are well finished and reach the market at a young age. The market demand for these ram lambs is excellent and they regularly receive top prices.

In North America it is often recommended that market lambs should not have more than 25-30% Finn breeding, because of carcass characteristics. However, surplus lambs from the two ARC dam strains, which contain 40-50% Finn, are also in demand and receive top prices in commercial markets.

4.11 NUTRITION OF THE BREEDING EWE

One of the major problems in an accelerated breeding program is to maintain the mating weight of the ewe over successive production cycles. This can be largely overcome by regulating the level of energy intake in relation to the physiological state of the ewe. Experience at ARC indicates that forage based diets, properly supplemented with minerals and vitamins are adequate to meet most of the energy requirements. Supplemental energy and/or protein, depending on the forage quality, are only required for relatively short periods when production demands are high, such as flushing in preparation for breeding, the last 4-5 weeks before lambing, and for the 4-6 weeks after lambing, during peak lactation[1].

4.12 ECONOMICS OF INTENSIVE LAMB PRODUCTION

An economic comparison has been made between a management intensive production system, which utilizes new technology and produces three lamb crops in 2 years and a more traditional system which produces a single lamb crop per year (115). In the latter system, intensive management of ewes and lambs for production improvement were minimized. Overall, intensification of the production system returned a higher net farm income than the traditional system, at high lamb prices. Because of its greater productivity, the intensive system was able to capitalize more effectively on increases in lamb prices. This meant that profitability could be increased at a faster rate than that of the traditional system. It was concluded from this study that the key components for an economically viable, management intensive, lamb production system, were increased lambing frequency combined with larger litter size and improved lamb survival. On the negative side, although a much higher production potential could be realized by intensification, it was also

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[1]Nutrient Requirements of Sheep. Sixth Revised Edition. 1985. National Academy Press, Washington, DC. 99 pp.

associated with a higher risk of financial loss due to increased costs of investment, labor, feed and other related expenses. Also, intensification of production required a much higher level of management capability and expertise than more traditional lamb production. Similar findings have been reported from a US study[1].

4.13 UTILIZATION OF THE TECHNOLOGY AND MANAGEMENT STRATEGIES

Despite the improvements in efficiency and/or output of lamb production which can be achieved from adoption of new technology, few of the components can be applied to the traditional extensive system of sheep management, which favors the seasonal production of a single lamb crop per year. Thus, some degree of intensification is required to utilize the technology available. The type of land, facilities, quantity and quality of labor, capital outlay, feed resources and management skills are key reference points in determining the type of production system, level of productivity and the extent to which new technology and management strategies can be utilized. The technology and the degree of intensification are highly flexible in meeting the objectives and special circumstances of producers. Overall, however, the level of productivity that can be achieved from existing or improved resources is determined largely by managerial ability.

4.14 POTENTIAL FOR ESTABLISHING PRODUCTIVE SHEEP MANAGEMENT

The Canadian sheep industry, as with other sectors of animal agriculture, is moving towards a greater degree of production efficiency. Diversified intensification perhaps best describes the direction in which the industry should be moving as production systems are developed to more efficiently utilize the diverse combinations of resources available. The competitive position of the industry and its ability to expand to achieve its potential will depend largely on how well it is able to incorporate the new innovations into lamb production systems.

Until now the industry has been slow to adopt the technology available because this would involve major changes in the sheep enterprise, increased capital outlay, considerable revision of management strategy and the inevitable element of risk. However, the more progressive sheep producers are beginning to recognize the potential of lamb production systems which can integrate new technology and management innovations to increase productivity and profitability. To assist in the implementation of new technology there is a need to organize and develop educational, management and flock health programs, to promote technology transfer and improve management capability and expertise.

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[1]Harrison, V.L. 1980. Sheep Production: Intensive Systems, Innovative Techniques Boost Yields. Agricultural Economic Report No. 452. Economics, Statistics and Cooperative Service, USDA, Washington, DC. 42 pp.

5. APPENDICES

APPENDIX A - THE PROGESTAGEN IMPREGNATED INTRAVAGINAL SPONGE FOR CONTROL OF REPRODUCTION

The development of the progestagen impregnated intravaginal sponge for synchronization of the estrous cycle offers new possibilities for increasing management efficiency and annual lamb output. The technique is simple to use, cheap and effective.

A.1 PRINCIPLE OF ACTION

The normal estrous cycle of the ewe (Figure 18) has two main parts. The FOLLICULAR PHASE which lasts 3-4 days and ends with estrus and ovulation. The LUTEAL PHASE which lasts 13-14 days, includes the development and regression of the corpus luteum. The beginning of the cycle is characterized by a period of ESTRUS or 'heat', which lasts 16-30h during which the ewe is sexually receptive. This can be readily determined using a ram fitted with a marking harness to mark the ewe. Onset of heat is designated day 0 of the cycle as a reference point for timing subsequent events. Ovulation occurs 24-30h later and is followed by the development of the corpus luteum which produces progesterone. The corpus luteum reaches its maximum size and functional activity by about day 7 and continues to produce progesterone, as indicated by elevated blood levels. If the ewe is not pregnant 13-14 days after ovulation,

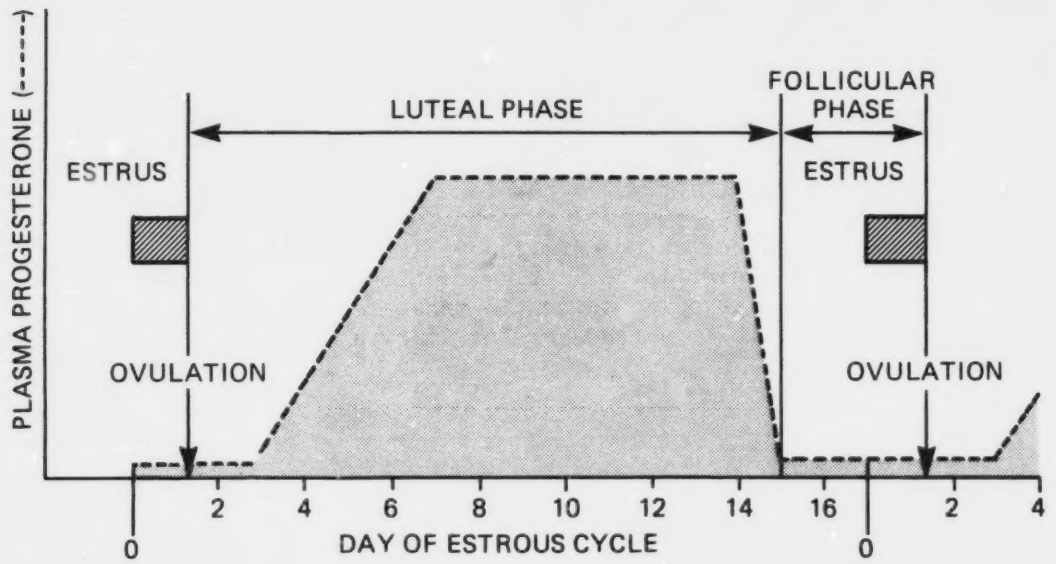

Figure 18. Schematic sequence of events during the estrous cycle of the ewe.

the corpus luteum ceases to produce progesterone, the blood progesterone level declines and a new estrous cycle, characterized by onset of heat, occurs within about 48h. The ewe will not come into estrus if the blood progesterone remains elevated as a result of pregnancy or during treatment with progesterone or progestagens, which are compounds with actions like those of progesterone.

The progestagen impregnated intravaginal sponge releases progestagen at a fairly steady and slow rate. Sufficient quantities of progestagen are absorbed by the vagina into the blood to mimic corpus luteum function for the duration of treatment. When the sponge is withdrawn, the source of progestagen is removed, triggering the start of a new follicular phase. The duration of sponge treatment is 14 days, corresponding to the normal lifespan of the corpus luteum. Thus, if treatment is applied to cycling animals during the breeding season, estrus and ovulation will be synchronized in all ewes (Figure 19).

Treatment of non-cycling animals with progestagen sponges creates an artificial luteal phase which corresponds to that of a normal estrous cycle (Figure 19). Removal of the sponge is followed by estrus and ovulation which is well synchronized, provided an adequate dose of PMSG is given at the time of sponge removal.

A.2 GUIDELINES FOR OPERATION

A.2.1 Initial Planning

Decisions are made on the number and suitability of ewes to be treated with the sponges, the time at which the ewes are to be bred, the feeding and husbandry methods to be used and the scheduling of procedures to avoid conflicts with other farm operations.

A.2.2 Insertion and Removal of Sponges

The standard treatment for control of the estrous cycle involves inserting a polyurethane sponge impregnated with a progestagen (see Figure 5A, page 17) into the vagina for 14 days. The procedures described in the following steps are shown in Figure 20.

A. The sponge is inserted into the front of the applicator leaving the string on the outside. The push rod is then placed in the rear of the applicator. If needed, a thin film of lubricant[1] is applied to the outside of the applicator. In most cases the lubricant is not needed for mature ewes that have previously lambed because there is usually little resistance to insertion of the applicator into the vagina.

B. The ewe is restrained in the standing position and the applicator carefully inserted into the vagina, in a slight upward direction at first, then gently but firmly pushed forward as far as possible.

C. Holding the push rod steady, the applicator is withdrawn a few cm. This ejects the sponge and positions it in the vagina.

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[1]Lubafax®, Burroughs Welcome Ltd., Montreal, Que., or equivalent.

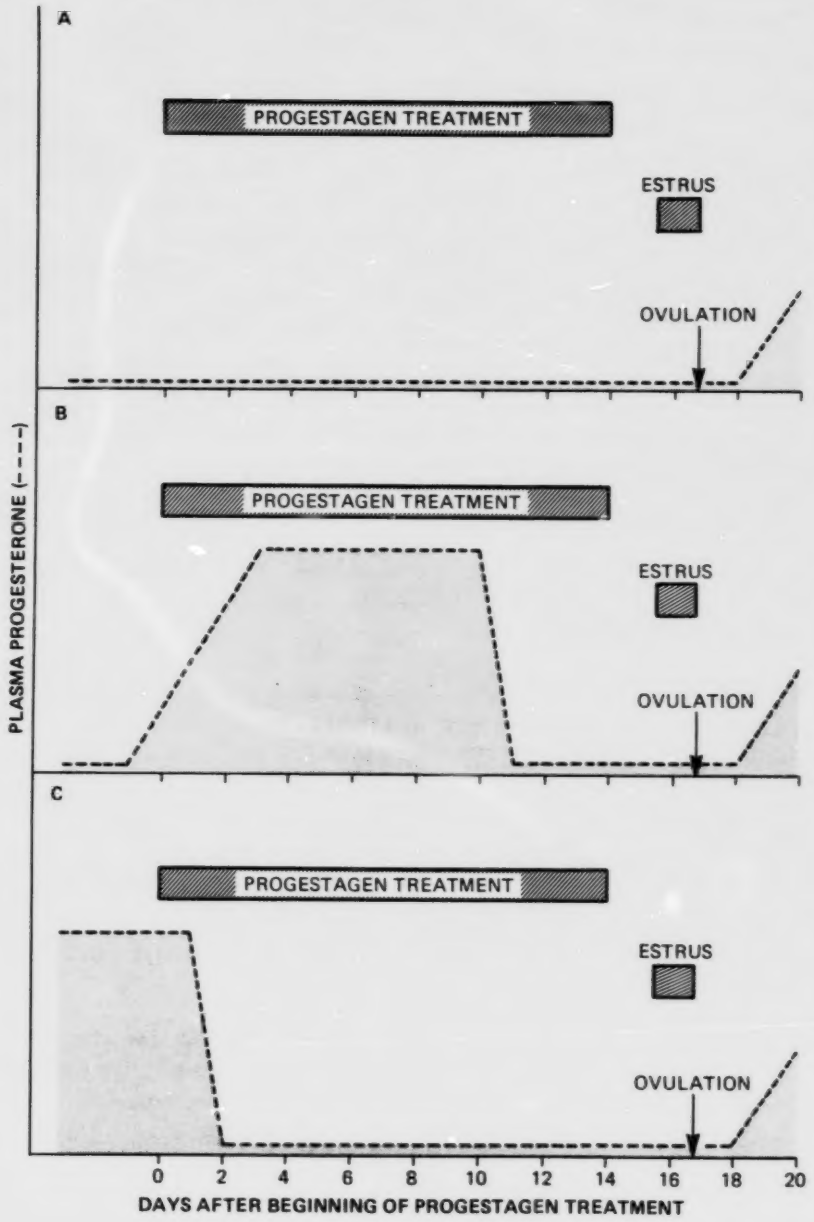

Figure 19. Onset of estrus and ovulation following treatment of ewes with progestagen-impregnated intravaginal sponges during the (A) nonbreeding season in the absence of cyclic activity; (B) breeding season early in the luteal phase of the estrous cycle; (C) breeding season late in the luteal phase of the estrous cycle.

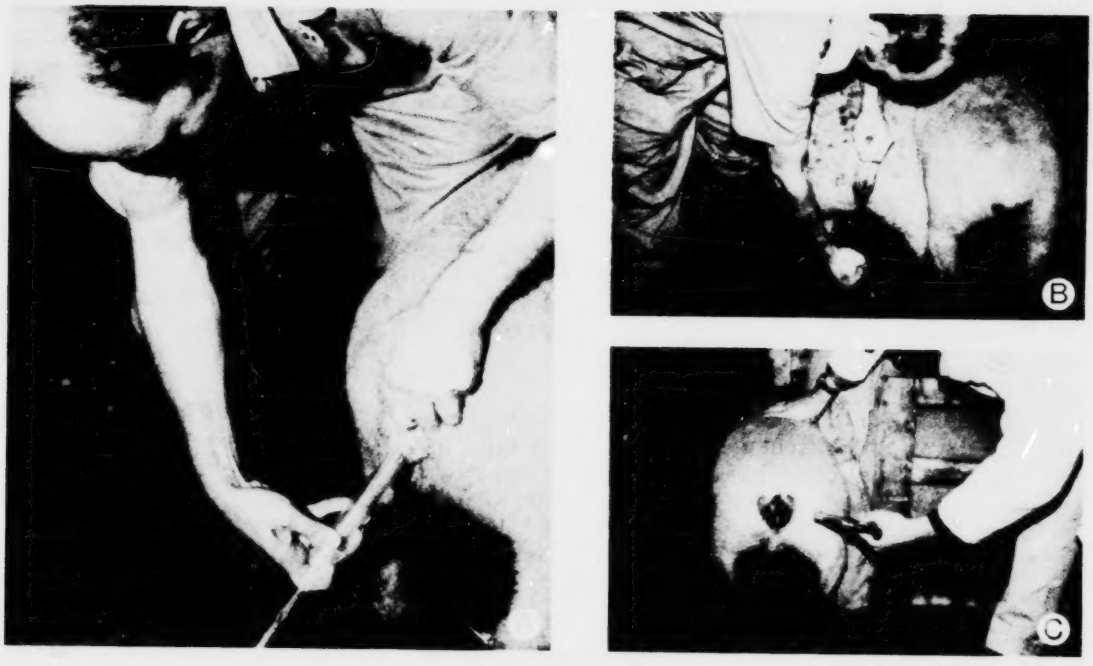

Figure 20. Synchronization of estrus technique. (A) Sponge insertion; (B) sponge removal; (C) PMSG injection with multi-dose syringe.

D. The push rod and applicator are removed leaving the drawstring hanging outside the vagina.

E. After each insertion, the applicator and push rod are rinsed in a bucket containing clean water and disinfectant[1], wiped and relubricated, if necessary.

F. After 14 days the sponge is removed by pulling gently on the string. It is usually accompanied by a variable amount of distinctive smelling fluid. This is due to accumulation of vaginal mucus which does not interfere with the ewe's health or subsequent conception.

- If no string is visible, a clean finger is inserted into the vagina to locate it. If the string or sponge cannot be felt, the vagina is examined using an empty applicator and a light. If the sponge is still in position, the string is teased out and the sponge removed.
- If the sponge cannot be removed by gentle pulling on the string, do not force it. Occasionally a sponge will adhere to the vaginal wall. In this case, a clean finger is used to gently separate the sponge from the vaginal wall before removal.
- Used sponges should be burned or buried.

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[1]Dettol®, Reckitt Colman Canada Inc., Lachine, Que., or equivalent.

A.2.3 Use of PMSG

Although ewes treated with intravaginal sponges during the breeding season will come into estrus shortly after sponge removal in the absence of PMSG, a low dose results in a more predictable and precise synchronization of estrus and ovulation, which is particularly important for AI. PMSG will also induce a mild superovulatory effect resulting in a small increase in the average litter size of ewes which conceive at the synchronized estrus.

For good lambing rates the use of PMSG is essential after sponge treatment of ewe lambs, adult ewes during seasonal or lactational anestrus and for AI. The usual dosage of PMSG is 500 IU injected intramuscularly when sponges are removed. The PMSG powder is stored in a refrigerator at 2-4°C and should not be dissolved until just before use, otherwise it will lose its activity.

A.2.4 Mating of Synchronized Ewes

Virtually all ewes will be in estrus by 48h after sponge removal. Natural mating is used to breed synchronized ewes in most controlled reproduction programs. Thus, the ram has to mate all of the ewes on the same day which means a short period of intensive work.

Because of the seasonal variation in the sexual capabilities of rams, the ratio of ewes to rams depends on the time of the year. During the normal breeding season (Sept-Jan) the treated ewes should be mated in groups of 10-12 ewes per ram. During the anestrous season (Feb-Aug) one ram to six ewes is recommended.

The rams are introduced 24h after sponge removal. Marking paint should be applied to the brisket of each ram to provide an indication of the number of ewes mated. If no ewes are marked within 36h after sponge removal the ram should be replaced.

Rams may be removed from progestagen treated ewes 72h after being introduced because by this time all the synchronized ewes should be mated. However, during the breeding season rams are usually left with the ewes for 23 days so that ewes which do not conceive at the synchronized estrus can be remated at the follow-up estrus. A ram can mate up to 40 ewes at the follow-up estrus because the ewes which did not conceive will tend to come into estrus over several days.

The number of ewes served by a particular ram can be increased by staggering the sponge treatment so that sponges are removed from groups of ewes at intervals of 5 days. The ram is then rotated among the groups of treated ewes. Using this procedure, three groups, each of 10-12 ewes, can be mated by the same ram over a 15 day period. The groups are then combined and the ram remains with the ewes for 21 days.

The schedule for synchronization of estrus, mating and lambing of ewes after treatment with progestagen impregnated intravaginal sponges and PMSG is illustrated in Figure 21. Conception occurs 3-4 days after sponge removal for first estrus pregnancies and approximately day 19 for second estrus pregnancies.

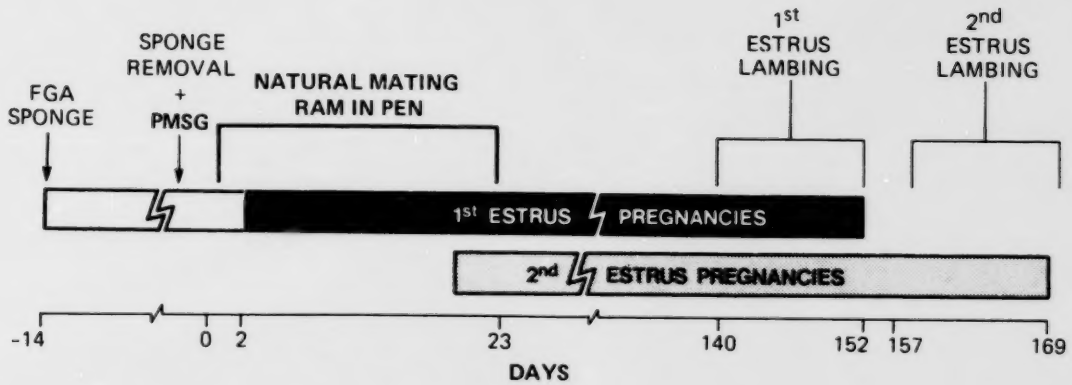

Figure 21. Schedule for synchronization of estrus, mating and lambing.

A.2.5 Feeding and Management of Ewes

A.2.5.1 Adult dry ewes. It is usual to flush the ewes beginning about 2 weeks before mating. This ensures that the ewes are in good condition, preferably gaining in body weight, and helps to increase the number of ovulations. The flushing diet should continue for about a month after mating because implantation of the embryo does not occur until about day 25 after conception. Nutritional stress during this time can increase embryonic mortality. Other stresses can also result in reduced fertility so ewes should be handled gently at the time of mating and operations like deworming, shearing or transport of ewes should be avoided during the 2 weeks before, and the 3-4 weeks after, mating.

Because the ewe's nutritional needs during early pregnancy are only slightly above maintenance, the flushing diet should be discontinued 2-4 weeks after mating. However, a sudden drop in the plane of nutrition should be avoided. From days 30-100 of pregnancy good quality forage, properly supplemented with minerals, or its equivalent is adequate. During the last stages of pregnancy a grain allowance of 120 g per day starting at day 100-110 of pregnancy and gradually increasing to 350 g per day by day 130-135 is recommended. The actual amounts may be varied depending on the quality of the forage and condition of the ewes.

Ultrasonic diagnosis (Appendix C) at 70-90 days after mating can be used to ensure that only pregnant ewes receive extra feed. The nonpregnant ewes can be separated for early culling, rebreeding or for maintenance feeding which can result in a saving of expensive feed and overhead costs.

Different breeds have predictable gestation periods and if ewes are all bred on the same day they will lamb within a 7-10 day period. Effective scheduling of available labor can ensure adequate care to minimize early lamb mortality.

At lambing, grain should be withheld for the first 24h but the ewe should have access to clean water and good, leafy hay. Next day, grain feeding is started and gradually increased for 5-7 days. However, if the ewe has little or no milk, she is allowed some grain and plenty of water the first day to try to bring her into milk. Ewes should be fed liberally 1-2 months after lambing when nutritional needs for lactation are highest. If possible, it is good practice to separate ewes nursing twins and feed them more than those nursing singles. A diet of 2 kg good quality hay plus 0.5-1 kg of grain daily (or equivalent), depending on size and condition of the ewe and whether she is nursing twins or a single lamb, is usually adequate.

A.2.5.2 Adult lactating ewes. If lactating ewes are mated in the spring after progestagen/PMSG treatment they rarely exhibit a repeat estrus. The fertility is usually lower than 50% because ovarian activity is depressed due to a combination of lactational and seasonal anestrus. This can be overcome to some extent by ensuring that the lactating ewe is not mated within 50 days of lambing. Preferably, the lambs should be weaned at least 2 weeks before starting sponge treatment. To reduce udder problems the level of feeding should be decreased about 3 days before weaning, water withheld for about 12h after weaning and only dry forage fed for 2-3 days. The ewes should then be brought up gradually to the flushing diet.

A.2.5.3 Ewe lambs. Ewe lambs can be mated at 6.5-7.5 months of age, depending on breed, provided they have reached about 70% of adult weight. This requires a high plane of nutrition throughout the growing period. Creep feed should be provided during nursing. After weaning a finishing type diet, containing 60-70% grain, should be fed until they are about 100-120 days of age. Then the grain should be reduced to about 40-50% of the total diet, depending on condition, to maintain rapid growth without excessive fattening.

If possible, ewe lambs should be mated separately from adult ewes. Behavior studies have indicated that rams prefer to mate adult ewes. Also, ewe lambs tend to come into estrus later than adult ewes after sponge treatment. Moreover, ewe lambs should be kept separate from adult ewes during pregnancy so that they can be given extra grain (125-250 g per day) to provide for continued growth.

A.2.6 Feeding and Management of Rams

A low level of feeding can reduce testicular size and spermatozoa reserves. Because production of spermatozoa takes 7-8 weeks, supplementary feeding of rams should start 2 months before mating to increase these reserves.

TABLE 7. Potential applications of the progestagen impregnated intravaginal sponge/PMSG treatment for management and control of reproduction

Application	Benefits
Advancing the breeding season	- produces compact lambing in Dec/Jan which allows rearing of a uniform lamb crop for the Easter market
Breeding ewe lambs	- improves production of lambs by one year of age - increases lifetime productivity - reduces maintenance costs before production - reduces generation interval which increases rate of genetic gain in selection programs
Set-time artificial insemination	- more widespread use of superior proven rams both within and between flocks - increases the ram power available at a synchronized estrus - reduces incidence of low conception due to ram subfertility
Increasing lambing frequency	- reduces generation interval - reduces maintenance costs per offspring reared - increases production per unit of capital investment - provides a more uniform supply of lambs

The success of a controlled reproduction program depends on the availability of an adequate number of active fertile rams. Also, procedures are available which allow rams of high fertility to be available year round (Appendix B).

A.3 APPLICATIONS AND BENEFITS OF CONTROLLED REPRODUCTION

Management and control of reproduction can help the producer increase the number of lambs produced and exercise control over the breeding and management of the flock (Table 7). Depending on the type of management program adopted, controlled reproduction offers the potential to improve fertility of ewe lambs at 7-8 months of age, lactating ewes or dry mature ewes year round and to intensify the management program by increasing the lambing frequency.

The outcome of controlled reproduction programs depends not only on the fertility and the timing of estrus and ovulation of the ewe, but also on the libido and fertility of the ram when natural service is used and on semen quality, numbers of spermatozoa and insemination procedures when AI is used. Nutrition, stress and the environment in general can also affect the outcome. However, as a general guide 65-75% of adult dry ewes treated in the fall can be expected to lamb from conception at the synchronized estrus and 15-25% from conception at the follow-up estrus. During spring or summer, fewer ewes will exhibit a repeat estrus if not pregnant after the synchronized estrus. This can be overcome to some extent by choice of breed, age, date of treatment, whether light control is used and nutritional status. The outcome of breeding ewe lambs and accelerated lambing programs are also very much dependent on the latter factors.

A.4 AVAILABILITY OF PROGESTAGEN IMPREGNATED INTRAVAGINAL SPONGES AND PMSG

Two types of intravaginal sponges are available. One type is impregnated with the synthetic progestagen FGA (see Figure 5A, page 17) and is sold under the trade name 'Chronogest'®[1]. The 'Chronogest' sponges are available in three preparations:

- impregnated with 30 mg FGA (grey in color). Used for adult ewes to induce and synchronize estrus and ovulation during seasonal anestrus.
- impregnated with 40 mg FGA (grey in color). Used for adult ewes to synchronize estrus and ovulation during the breeding season and during lactational anestrus.
- impregnated with 40 mg FGA (white in color). Used for ewe lambs to induce and/or synchronize estrus and ovulation depending on age and season.

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[1]Intervet, S.A., Angers, France.

The second type of intravaginal sponge is impregnated with 60 mg MAP (see Figure 5B, page 17) and is available under the trade name 'Veramix'®[1]. The 'Veramix' sponge is available as a single preparation. At the present time, only the 'Veramix' sponge is registered for use in Canada.

PMSG is available in Canada under the trade names 'Equinex'®[2] and 'Stimukron'®[3].

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[1]Tuco Products Company, Division of Upjohn, Orangeville, Ont.

[2]Ayerst Laboratories, Montreal, Que.

[3]P.V.U. Inc., Victoriaville, Que.

APPENDIX B - TRAINING AND SELECTION OF RAMS, COLLECTION AND PROCESSING OF SEMEN AND BREEDING BY AI

B.1 RAM LIBIDO AND SEMEN PRODUCTION

Although rams do not show a restricted breeding season there are seasonal variations in testis size, spermatozoa production and semen output and quality. In northern latitudes, semen quality and libido are highest in the fall and winter when the daylength becomes shorter and lowest in spring and summer when the daylength becomes longer. These fluctuations can be reduced by exposing rams to a teaser ewe at weekly or biweekly intervals during the non-breeding season, by regular and frequent semen collections (2-3 times weekly) and by the use of controlled light programs (see page 23).

Elevated body temperatures during hot days can also cause a reduction in semen quality and temporary infertility. Thus, during hot weather shelter should be available to keep rams cool. They should also be sheared and all the wool taken off the scrotum at least 2 months before they are to be used for breeding or AI during the spring or summer months.

Ram lambs have significantly lower semen production than adults. Also, ram lambs with no natural mating experience take longer to train, produce smaller ejaculates and require more mounts per ejaculate during their first year of use.

B.2 TRAINING OF RAMS FOR SEMEN COLLECTION

Semen may be collected throughout the year by using a teaser ewe (Figure 22A) and an artificial vagina (AV) (Figure 22B), or by electro-ejaculation. Collection by an AV is preferred to electro-ejaculation because of consistently better semen quality and the ability to collect several ejaculates within a short period of time. Most adult rams can be readily trained to mount a teaser ewe for collection of semen with an AV. The time taken to train a ram to mount a teaser ewe varies with season, age, sexual experience, previous handling and behavior.

Initially, teaser ewes are introduced to the rams for 2-3h twice a day for up to a week. Rams are then encouraged to mount a teaser ewe that is restrained quietly in a standing position in the presence of a semen collector. Once this has been accomplished the ram can be readily trained to serve an AV (Figure 22A). Ram lambs or rams with low libido can often be trained more quickly by allowing them to watch other rams mounting. An ovariectomized ewe makes a convenient teaser because it can be brought into estrus, when required, by intramuscular injection of 1 mg estradiol cypionate[1]. Symptoms of estrus are observed 24-48h after treatment and last for up to 24h.

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[1] ECP®: Tuco Products Company, Division of Upjohn, Orangeville, Ont.

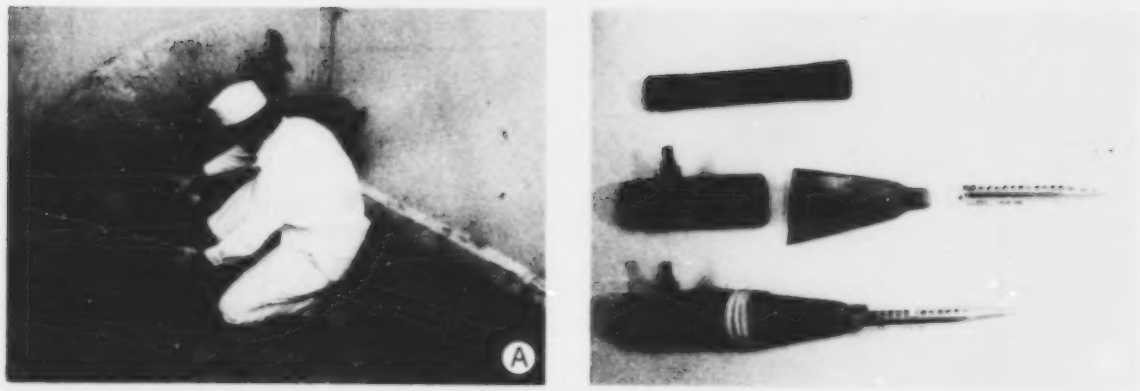

Figure 22. (A) Collection of ram semen using an artificial vagina and a restrained teaser ewe; (B) components and assembled artificial vagina.

B.3 SELECTION OF RAMS AS SEMEN DONORS

Selection of rams is based on the quality of ejaculated semen and, to a lesser extent, on their ability to be trained to use an AV. Careful screening of the rams is required if the semen collected is to be frozen. Studies have shown large variations in the ability of spermatozoa from different rams to survive freezing and thawing. Overall, about two thirds of the rams selected as semen donors will produce semen which can be frozen satisfactorily, i.e. at least 35% of the spermatozoa are alive and have a satisfactory motility rating (3.5 or above) after freezing and thawing. Some ejaculates with acceptable freezability have spermatozoa concentrations lower than 3.0 billion per ml. These ejaculates are usually not suitable for freezing because the number of spermatozoa which survive is insufficient for AI.

B.4 COLLECTION AND PROCESSING OF SEMEN

Fresh semen for AI must be collected and processed on the day it is to be used. Only rams yielding ejaculates of high quality should contribute. Several ejaculates are usually possible during a 2-5 min collection period.

Following collection, the ejaculates are maintained at 30°C and assessed for volume, spermatozoa concentration and motility. Spermatozoa concentration

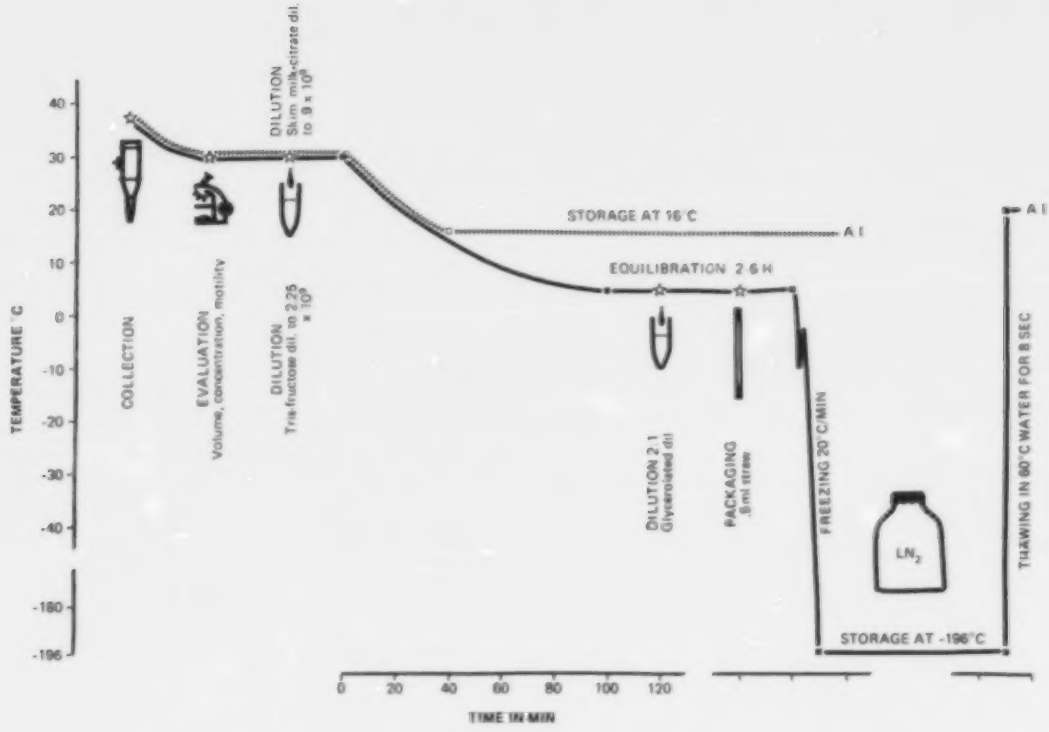

Figure 23. Procedures for processing ram semen. Dotted line=fresh semen: Solid line=frozen semen.

is determined with a spectrophotometer, principally to calculate the appropriate dilution for AI. Spermatozoa motility is assessed with a microscope as percentage of motile spermatozoa (0-100%) and rate of forward progression (motility rating) on a scale of 0-5 (0, no movement; 5, very fast movement). Usually a semen sample with a percent motility of at least 70% and a motility rating of at least 4.0 will be suitable for AI.

Semen to be used fresh is extended with a skim milk-citrate diluent (Table 8) to a spermatozoa concentration of 900 million per ml and cooled to 16°C, at a rate not faster than 0.3°C per min (Figure 23). Extended semen can be kept for up to 12h without any appreciable loss of fertilizing capability. The diluent provides nutrients for the spermatozoa, buffering against changes in pH, electrolyte balance and protection against 'cold shock' when the semen is cooled to the storage temperature. A single ejaculate can be extended and used to inseminate up to 12 ewes.

Semen to be frozen is extended initially to a concentration of 2.2-2.3 billion spermatozoa per ml with Tris-fructose diluent (Table 8) at 30°C. The extended semen is cooled to 5°C, at a rate not faster than 0.3°C per min. It is then further extended over 30 min by dropwise addition of one part

TABLE 8. Composition of diluents used for processing of ram semen

For fresh semen and for assessment of frozen semen		
Skim milk-citrate diluent[a]		
Skim milk powder	110.00	g
0.8 mM sodium citrate dihydrate	6.69	ml
Penicillin G	240 000	IU
Dihydrostreptomycin	300	mg
Sterile distilled water	to 1	liter
For frozen semen		
Tris-fructose diluent[b]		
THAM (Tris(hydroxymethyl)aminomethane)	32.56	g
D-Fructose	9.35	g
Citric acid	17.02	g
Glycerol	20.00	ml
Penicillin G	500 000	IU
Dihydrostreptomycin	625	mg
Sterile distilled water	to 1	liter
Glycerolated diluent[c]		
Dextran B (150 000-200 000 MW)	39.53	g
Sodium citrate dihydrate	6.88	g
TES (N-tris(hydroxymethyl)methyl-2-aminoethane sulfonic acid)	1.58	g
Glycine	3.63	g
Lactose	101.88	g
Raffinose	11.86	g
Fructose	5.06	g
Glycerol	120.00	ml
Penicillin G	500 000	IU
Dihydrostreptomycin	625	mg
Sterile distilled water	to 1	liter

[a]The skim milk powder and distilled water are heated to 92°C for 10 min to destroy a spermicidal factor, lactenin, present in the milk. Care should be taken to avoid overheating or boiling the diluent. After cooling, the sodium citrate and antibiotics are added. The diluent may be stored up to 3 days in the refrigerator after which it should be discarded and a fresh batch prepared.

[b]The dry ingredients are dissolved in sterile distilled water. Glycerol is then added and the volume made to 1 liter with sterile distilled water. This stock solution may be stored in a refrigerator for up to 14 days. For use, eight parts of the stock solution are mixed with two parts egg yolk.

[c]The dry ingredients are dissolved in sterile distilled water. Glycerol is then added and the volume made to 1 liter with sterile distilled water. The diluent may be stored in a refrigerator for up to 14 days.

glycerolated diluent (Table 8) to two parts Tris-fructose extended semen. After transfer into 0.5 ml plastic straws and equilibration at 5°C for a further 2-6h, the extended semen is frozen to -100°C using a programmable freezer at a rate of 20°C per min before transfer to liquid nitrogen (-196°C) for storage (Figure 23).

For routine assessment, straws containing frozen extended semen are thawed in a water bath at 60°C for 8 sec and the contents emptied into 2 ml of the skim milk-citrate diluent (Table 8) at 37°C. Spermatozoa motility parameters are estimated immediately after thawing and again after incubation for 2h at 37°C. Only batches of semen containing at least 35% motile spermatozoa after freezing and thawing are used for AI. Straws to be used for AI are thawed, just prior to use, by the same procedure. The thawed extended semen is inseminated without further dilution.

B.5 ARTIFICIAL INSEMINATION

AI is not a practical proposition under farm conditions in North America unless it can be used in conjunction with estrous synchronization to allow AI of a group of ewes at a pre-determined time. When breeding by AI, each ewe is inseminated 55h after sponge removal and PMSG administration with 0.5 ml extended semen containing a minimum of 300 million motile spermatozoa (Figure 24). Adult ewes inseminated with fresh semen have consistently had lambing rates of 65-70% which are comparable to those obtained by natural service at the synchronized estrus.

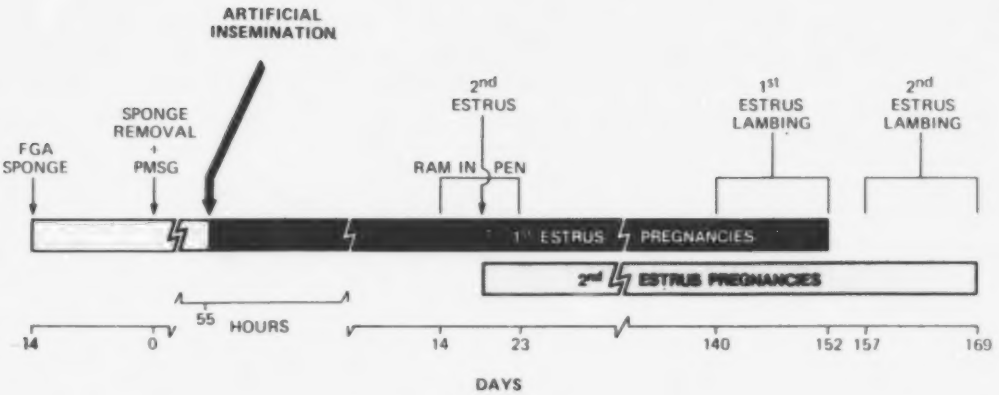

Figure 24. Breeding and lambing schedule for ewes bred by AI at the synchronized estrus and by natural service at the follow-up estrus.

Figure 25. Visual location of cervix and artificial insemination.

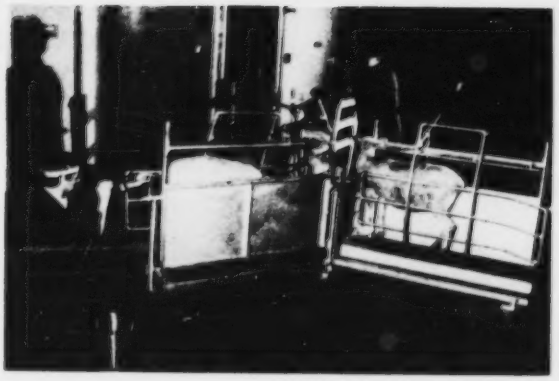

Figure 26. Rotating carousel for artificial insemination of large numbers of ewes.

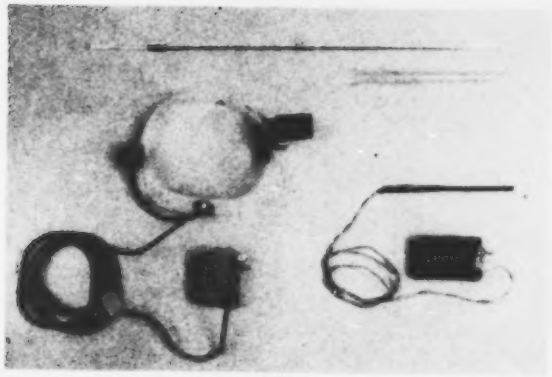

Figure 27. Headlight and battery operated pen light for artificial insemination.

Insemination of sheep is more difficult than for cattle because rectal palpation to find the cervix is impossible and semen cannot be deposited directly into the uterus because of the small, highly convoluted cervix. The inseminator must visually locate the cervix (Figure 25) and then deposit the semen into the external cervical opening or, if possible, the first cervical fold.

Suitable ewe handing facilities are necessary to allow AI to be carried out with as little disturbance as possible, because stress from excessive handling can reduce conception rates. For inseminating large numbers, the ewes are confined in squeeze chutes on a rotating carousel (Figure 26) which greatly reduces labor and speeds up AI. While one ewe is being inseminated, another is being loaded and the ewe just inseminated is unloaded. The carousel is then rotated to the next position for AI. With this equipment 60-80 ewes can be inseminated per hour.

When small numbers of ewes are to be inseminated it is satisfactory to restrain the ewe by lifting her hind quarters over a rail or a bale of hay or straw while the cervix is located and the semen is inseminated. A battery operated pen light fitted to the applicator used for inserting sponges, or a headlight and applicator, are effective methods for locating the cervix (Figure 27). A duckbilled speculum is an acceptable alternative, but in this case it is essential the hindquarters of the ewe are raised.

APPENDIX C - PREGNANCY DIAGNOSIS OF SYNCHRONIZED EWES WITH PORTABLE ULTRASOUND EQUIPMENT

Pregnancy diagnosis of ewes should be carried out about 70 days after sponge removal (Figure 28). The ewe is restrained in a standing position. To locate the fluid filled pregnant uterus, the probe is placed on the right side of the abdomen (to avoid the rumen), several centimeters in front of the teat, in an area clear of wool (Figure 29). Several drops of vegetable or mineral oil are put on the probe to improve contact with the skin and exclude air. Occasionally, the probe has to be repositioned before proper skin contact is made and a clear signal obtained. The probe emits ultrasonic pulses and picks up their echoes. When ultrasonic signals pass through fluid-filled areas such as the pregnant uterus, no echo is produced, so failure to detect an echo indicates pregnancy. Care must be taken to direct the probe slightly forward and approximately 45° upward across the abdomen, aimed at a point on the left side behind the last rib. Otherwise the signals will pass through the urinary bladder, behind the uterus.

To increase the reliability of diagnosis, water should be withheld for at least 12h before testing. Ewes diagnosed as pregnant 70 days after sponge removal may be segragated since a positive diagnosis at this time is about 95% accurate. Ewes diagnosed as not pregnant should be retested about 3 weeks later. By retesting, virtually all pregnant ewes are identified and unrecognized pregnancies are reduced to about 1%.

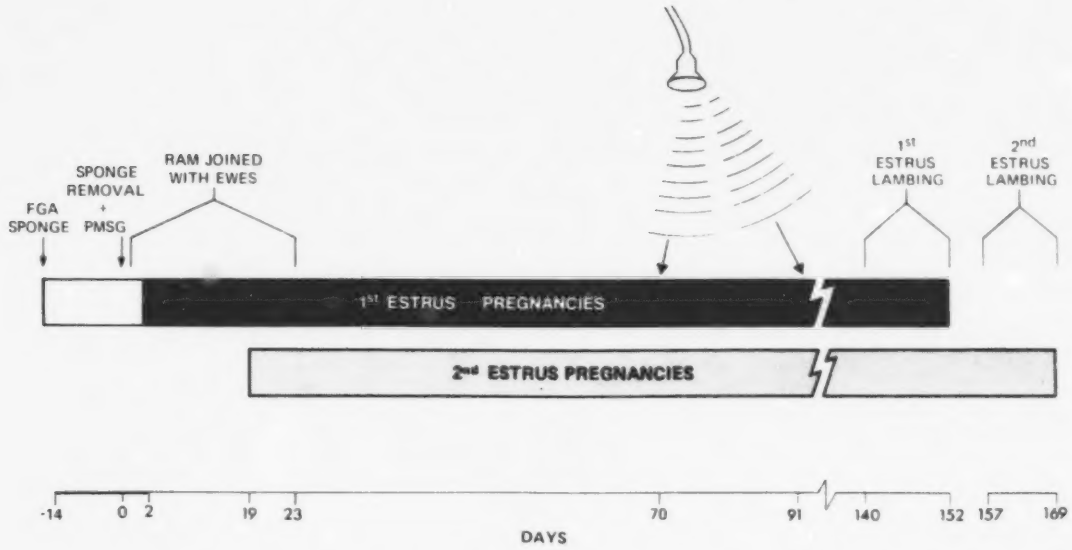

Figure 28. Schedule for ultrasonic pregnancy testing of estrous synchronized ewes. (From Ref. 143).

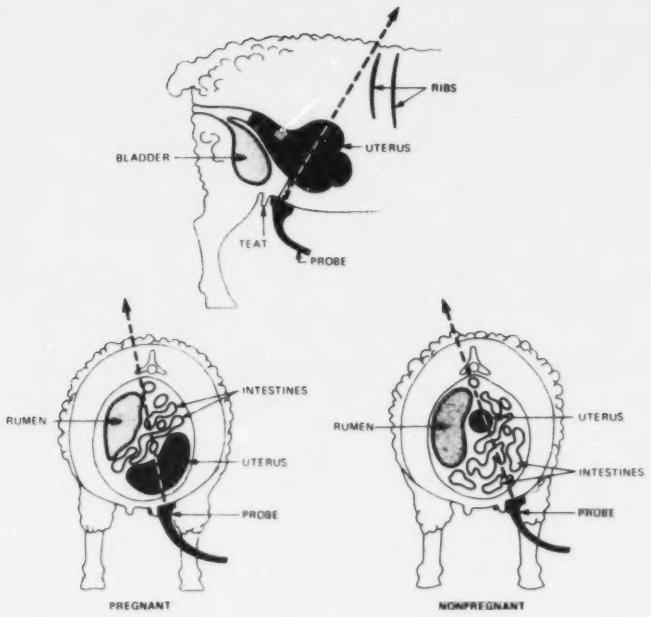

Figure 29. Schematic location of ultrasonic probe for pregnancy testing. (From Ref. 143).

The main reason a few pregnant ewes are not detected initially at day 70 is because they conceived at the second estrus and are about 51 days pregnant when first tested (Figure 28), but are about 72 days pregnant when retested. Experience has shown that single pregnancies are missed more often than multiple pregnancies when ewes are pregnant for less than 70 days. The relative ease with which litters of two or more lambs can be detected early in pregnancy is probably due to the greater volume of fetal fluids in the uterus.

Of the ultrasound equipment tested and evaluated at ARC the most reliable in terms of ease of operation and accuracy of diagnosis has been the Scanopreg II®[1].

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[1]Model 738®, Scanco Inc., Ithaca, NY.

APPENDIX D - ARTIFICIAL REARING OF LAMBS

Artificial rearing is the practice of removing very young lambs from their mothers and raising them on milk replacer. The practice is increasing, probably because of the use of prolific breeds which produce more lambs than the ewes can raise themselves. Management is the most important single factor which determines the success of an artificial rearing operation. While an Agriculture Canada Publication[1] is a valuable guide, research at ARC has provided additional information which can improve the efficiency and/or lower the cost of artificial rearing. This section incorporates these research findings into recommendations for artificial rearing systems.

D.1 CHOICE OF MILK REPLACER

Best performance is obtained by feeding specially formulated lamb milk replacers, now available from several major feed companies, which contain at least 24% fat. Higher levels of fat (up to 30% is often recommended and used) are not needed and unnecessarily increase the price (see page 13). All the protein should be provided by spray dried milk products. The fat can be provided by combinations of high quality tallow, lard, butterfat, coconut oil or soybean oil. Other vegetable oils are not recommended.

Lambs can be successfully reared with whole cow's milk, if a cheap source is available, or high quality calf milk replacer. However, only high quality calf milk replacers (defined as those with at least 20% fat and 20% protein, provided by spray dried milk products) should be considered. Lower quality and, hence, less expensive calf milk replacers often contain less fat and/or protein, or part of the protein may be provided by plant products. Such lower quality products should be avoided because it is doubtful that they would be satisfactory for lambs. Although gains on whole cow's milk or calf milk replacers are about 90% of those achieved with specially formulated lamb milk replacers (see page 14), the use of these products can be economical because the lower cost can offset the marginal reduction in lamb performance.

D.2 MIXING AND FEEDING MILK REPLACER

Commercial milk replacers should be reconstituted according to the manufacturer's instructions. Usually, one part by weight of powder to four or five parts by weight of water will give the 16-20% solids recommended. Mixing is easier if warm water is used. The mixed milk replacer should be cooled to about 4°C for storage or before feeding to lambs if a cold milk replacer feeding system is used.

A small number of lambs may be fed by hand. However, if more than a few animals are involved, an ad libitum feeding system is needed to reduce the high labor costs. Many systems, ranging from multiple nipple pails to teat bars to sophisticated pipelines, are available. The choice of system depends on the number of lambs to be reared and individual circumstances or

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[1]Artificial Rearing of Young Lambs. 1982. Communications Branch, Agriculture Canada, Ottawa, Ont. Publ. 1507E. 25 pp.

preferences. Regardless of the ad libitum feeding system adopted, each nipple can feed several lambs. For ad libitum feeding it has been recommended that milk replacer be fed cold to eliminate digestive disturbances, such as abomasal bloat. However, research at ARC has shown that the addition of 0.05-0.1% formalin to reconstituted milk replacer not only retards bacterial growth and souring, but also eliminates digestive disturbances (see page 14) indicating that milk replacer can be fed safely ad libitum at room temperature. The choice, therefore, depends on the overall cost.

D.3 MANAGEMENT

Lambs to be reared artificially should be allowed to nurse their mother for at least 6h following birth to obtain colostrum. Colostrum is essential to provide the antibodies needed to resist disease and infection. It is also a mild laxative which helps start normal bowel movement and is rich in nutrients. If, for any reason, sufficient colostrum is not available it can be provided from another ewe. Frozen colostrum, warmed to body temperature and bottle fed, is an adequate alternative. Although frozen ewe colostrum is preferred, cow colostrum also provides adequate antibodies for rearing lambs. At least 50 ml colostrum per kg of lamb weight is needed to provide effective disease resistance.

The artificial rearing facilities should be warm, dry and draft free. The lambs should not be able to see or hear their dams. Most lambs need to be trained to nurse by placing a nipple in their mouth and moving their jaws to stimulate sucking. Several sessions, a few hours apart, are usually sufficient. While it is important to ensure each lamb learns to nurse independently, excessive handling should be avoided or they may become conditioned to drink only when an attendant is present. The sooner the lambs are removed from the ewes, after getting colostrum, the easier they will be to train. Leaving the lambs for several hours before they are introduced to the artificial teat also makes training easier and often one or two training sessions is enough.

It is very important that lambs have access to both water and a palatable, high quality creep feed at all times to accustom them to eating dry feed and to stimulate rumen development. It is also important at weaning to be sure that all lambs have found the water. Experience at ARC has shown that some lambs that have been doing well on milk replacer have not started drinking water. If corrective action is not taken, dehydration can result in death.

D.4 WEAN LAMBS EARLY

Because milk replacer is expensive, liquid feeding should be as short as possible to reduce costs. Lambs should be weaned from milk replacer at 21 days of age. Although a delay in weaning to 28 days of age will result in lambs that are approximately 1 kg heavier at 70-90 days of age, the extra weight does not cover the cost of the additional milk replacer required (see page 13). Thus, a delay in weaning for an extra week cannot be justified economically. Possible exceptions to this are lambs which are still very small at 21 days of age. Experience at ARC has shown that lambs less than 6 kg liveweight benefit from an extra week on milk replacer.

APPENDIX E - SPECIAL TECHNIQUES AND EQUIPMENT FOR STUDIES OF DIGESTION AND ABSORPTION OF NUTRIENTS

A plastic metabolism cage for sheep (68) has been developed at ARC (Figure 30B). The cage is suitable for experimental work with trace minerals because it contains no metal parts. Also, it was designed to provide easy access to reentrant cannulae and rumen fistulae. It can be quickly washed and decontaminated after use for studies with radioisotopes.

An automated feeder (156) has been developed in cooperation with engineers from the Engineering and Statistical Research Centre of Agriculture Canada. The feeder (Figure 31A) provides controlled individual feed delivery to one or two sheep in metabolism cages or floor pens.

Reentrant cannulation techniques for the small intestine of sheep (Figure 30A) have been developed in cooperation with the National Research Council of Canada (85). A unique cannula has been fully evaluated and is available commercially[1]. The cannula is inserted into the intestinal tract through a small incision. The intestinal tract does not have to be severed completely, which minimizes interference with the normal peristalsis (149). The cannula can be used for continuous collection, sampling and return of digesta to the intestinal tract.

To complement the reentrant cannula, a versatile, automated system for sampling duodenal digesta has been developed, in cooperation with the Engineering and Statistical Research Centre. The system (125,161) includes a sampling apparatus (Figure 31B) which is programmable and can operate under anaerobic conditions. The digesta from a sheep is pumped into the apparatus, mixed, sampled, then blown to the return system positioned over the animal. The digesta then flows by gravity back into the intestine, after donor digesta has been added to compensate for the sample taken. Digesta is automatically refrigerated upon entering the apparatus and is warmed to body temperature before return to the animal. The flow rate and time of sampling can be recorded. The digesta from one animal can be returned to the same (Figure 31C) or to another animal (Figure 31D). The apparatus is convertible for use with sheep or cattle, under aerobic or anaerobic conditions. It is easily washed and decontaminated.

The plastic cage, automated feeder, reentrant cannulation and digesta sampling system, are essential components of the techniques used for basic and applied studies of digestive processes in ruminants.

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[1]Ketchum Manufacturing Sales Ltd., Ottawa, Ont.

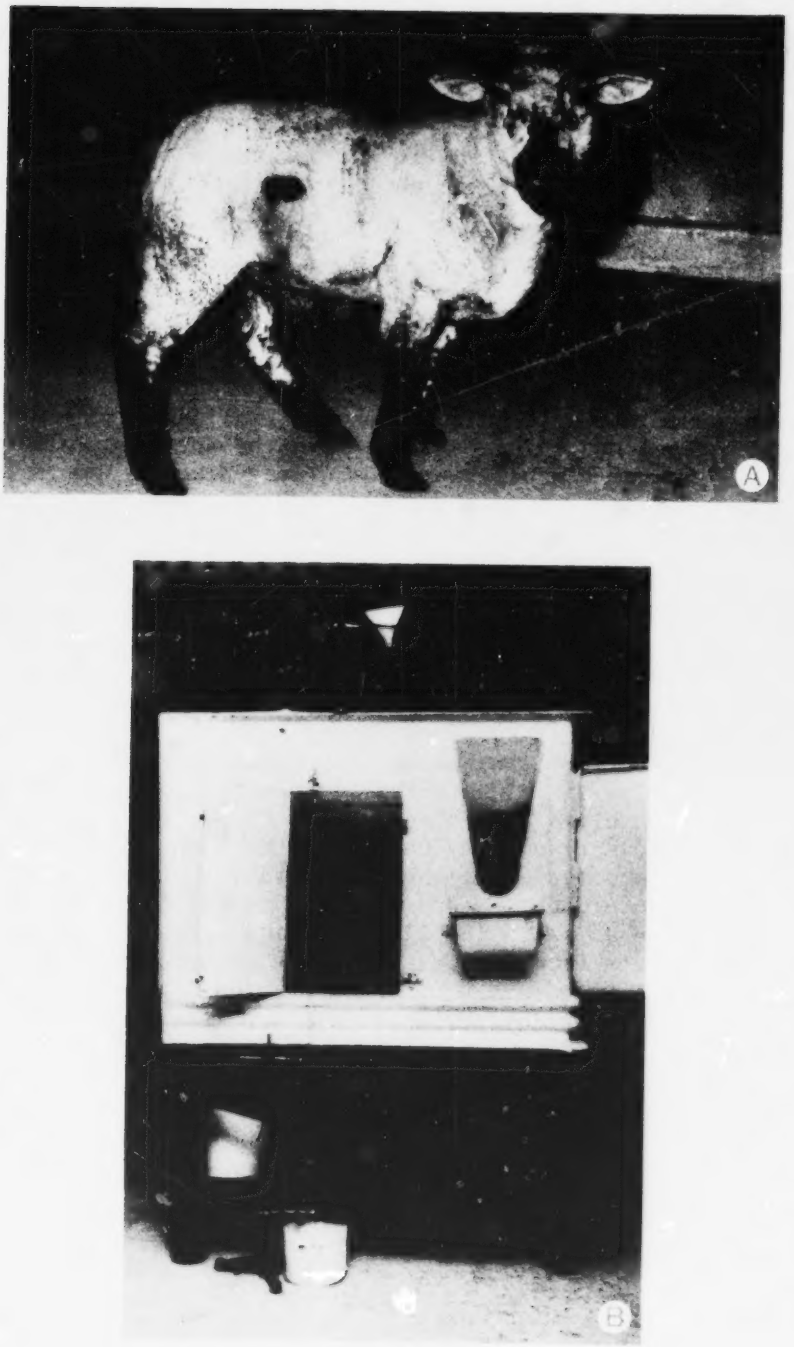

Figure 30. (A) Sheep with duodenal reentrant cannula; (B) metabolism cage showing collection of digesta.

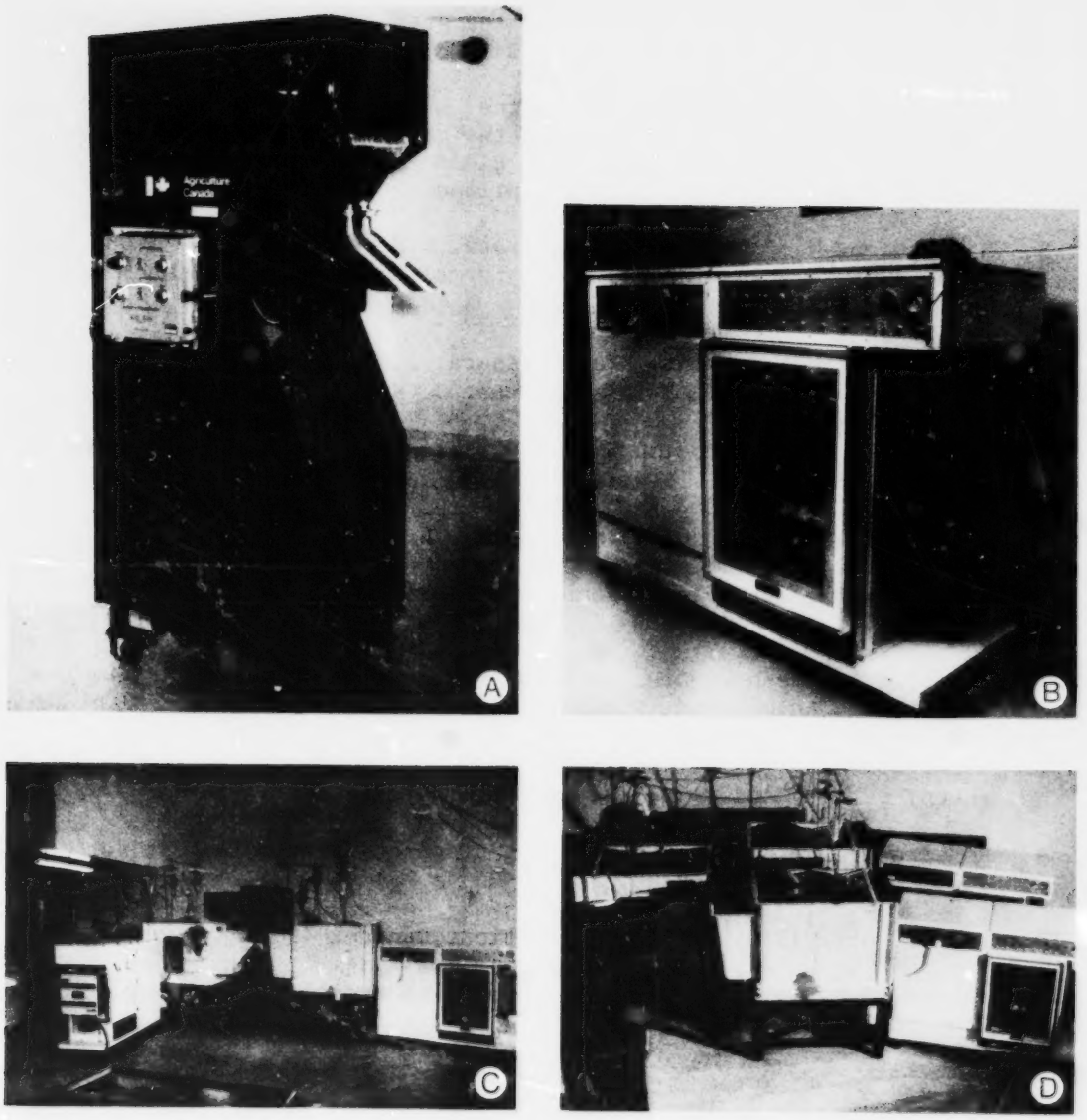

Figure 31. (A) Automatic feeding device for controlled feeding; (B) automated duodenal digesta sampling system; (C) use of (A) and (B) for continuously fed individual sheep; (D) a set of three sheep exchanging digesta. (From Ref. 161).

6. BIBLIOGRAPHY

*An asterisk indicates the reference is cited in the text.

1968-70

1. Hidiroglou, M.; Hoffman, I.; Jenkins, K.J. 1969. Selenium distribution and radiotocopherol metabolism in the pregnant ewe and fetal lamb. Can. J. Physiol. Pharmacol. 47:953-962.

2. Hidiroglou, M.; Hoffman, I.; Jenkins, K.J. 1970. Selenium distribution and radiotocopherol metabolism in the pregnant ewe and foetal lamb. Pages 272-274 in Mills, C.F. ed., Trace Element Metabolism in Animals. E. & S. Livingston, Edinburgh, Scotland.

3. Hidiroglou, M.; Jenkins, K.J.; Carson, R.B.; Mackay, R.R. 1968. Some aspects of selenium metabolism in normal and dystrophic sheep. Can. J. Anim. Sci. 48:335-346.

4. Hidiroglou, M.; Jenkins, K.J.; Lessard, J.R.; Carson, R.B. 1970. Metabolism of vitamin E in sheep. Br. J. Nutr. 24:917-928.

5. Jenkins, K.J.; Hidiroglou, M. 1968. Selenium - poison and essential element. Can. Agric. 13(4):18-20.

6. Jenkins, K.J.; Hidiroglou, M.; Mackay, R.R.; Proulx, J.G. 1970. Influence of selenium and linoleic acid on the development of nutritional muscular dystrophy in beef calves, lambs and rabbits. Can. J. Anim. Sci. 50:137-146.

7.* Lodge, G.A.; Heaney, D.P. 1970. Energy cost of pregnancy in the ewe. Eur. Assoc. Anim. Prod. Publ. 13:109-112.

8. Robertson, H.A. 1970. The endogenous control of oestrus and ovulation in sheep, cattle, and swine. Vitam. Horm. 27:91-130.

9. Robertson, H.A. 1970. A very early pregnancy diagnosis test for livestock. Canadex 400.30.

10. Peters, H.F. 1970. Sheep reproduction. Canadex 430.

11. Peters, H.F. 1970. Management approach to economic lamb production. Can. Wool Grower XL(4):11.

1971-72

12. Hidiroglou, M.; Hoffman, I.; Jenkins, K.J.; Mackay, R.R. 1971. Control of nutritional muscular dystrophy in lambs by selenium implantation. Anim. Prod. 13:315-321.

13. Hidiroglou, M.; Jenkins, K.J. 1971. Serum levels of magnesium, iron, and zinc in normal and dystrophic sheep. Can. J. Anim. Sci. 51:803-806.

14. Hidiroglou, M.; Jenkins, K.J. 1971. Pellets control nutritional muscular dystrophy (NMD). Canadex 401.660.

15. Hidiroglou, M.; Jenkins, K.J. 1972. The effects of phytol and ethanol on the fate of radiotocopherol in sheep. Can. J. Anim. Sci. 52:505-510.

16. Hidiroglou, M.; Jenkins, K.J.; Corner, A.H. 1972. Control of nutritional muscular dystrophy in lambs by vitamin E implantations. Can. J. Anim. Sci. 52:511-516.

17. Jenkins, K.J.; Hidiroglou, M. 1971. Transmission of selenium as selenite and as selenomethionine from ewe to lamb via milk using selenium-75. Can. J. Anim. Sci. 51:389-403.

18. Jenkins, K.J.; Hidiroglou, M. 1972. A review of selenium/vitamin E responsive problems in livestock: A case for selenium as a feed additive in Canada. Can. J. Anim. Sci. 52:591-620.

19. Jenkins, K.J.; Hidiroglou, M. 1972. Selenium-vitamin E deficiency in livestock. Canadex 400.51.

20. Robertson, H.A.; Sarda, I.R. 1971. A very early pregnancy test for mammals. Its application to the cow, ewe and sow. J. Endocrinol. 49:407-419.

1973-74

21.* Gowe, R.S.; Barr, G.R.; Peters, H.F. 1974. A multi-disciplinary approach to the development of intensive animal systems for Canada. Proc. Br. Soc. Anim. Prod. 3:69-83.

22. Heaney, D.P.; Lodge, G.A. 1974. Energy metabolism during late pregnancy in the ewe. Eur. Assoc. Anim. Prod. Publ. 14:123-126.

23. Hidiroglou, M.; Jenkins, K.J. 1973. Influence de la défaunation sur l'utilisation de la sélénométhionine chez le mouton. Ann. Biol. Anim. Biochim. Biophys. 14:157-165.

24. Jenkins, K.J.; Hidiroglou, M.; Wauthy, J.M.; Proulx, J.E. 1974. Prevention of nutritional muscular dystrophy in calves and lambs by selenium and vitamin E additions to the maternal mineral supplement. Can. J. Anim. Sci. 54:49-60.

25.* Lodge, G.A.; Heaney, D.P. 1973. Composition of weight change in the pregnant ewe. Can. J. Anim. Sci. 53:95-105.

26.* Lodge, G.A.; Heaney, D.P. 1973. The energy cost of pregnancy in single and twin-bearing ewes. Can. J. Anim. Sci. 53:479-489.

27.* Peters, H.F.; Heaney, D.P. 1974. Factors influencing the growth of lambs reared artificially or with their dams. Can. J. Anim. Sci. 54:9-18.

28.* Peters, H.F.; Heaney, D.P. 1974. Heterosis, breed-of-sire and breed-of-dam effects on growth rates of lambs reared artificially or with their dams. Can. J. Anim. Sci. 54:19-22.

29. Sarda, I.R.; Robertson, H.A.; Smeaton, T.C. 1973. Sequential changes in plasma progesterone levels in the ewe during the estrous cycle, and during pregnancy in intact and ovariectomized sheep. Can. J. Anim. Sci. 53:25-34.

30. Tsang, C.P.W. 1974. Changes in plasma levels of estrone sulphate and estrone in the pregnant ewe around parturition. Steroids 23:855-868.

31. Walton, P.; Robertson, H.A. 1974. The reproductive performance of Finnish Landrace ewes mated twice yearly. Can. J. Anim. Sci. 54:35-40.

1975-76

32.* Heaney, D.P.; Ibrahim, E.A. 1975. Rumen development in artificially reared lambs. Can. J. Anim. Sci. 55:476 (Abstract).

33.* Heaney, D.P.; Lodge, G.A. 1975. Body composition and energy metabolism during late pregnancy in the ad libitum fed ewe. Can. J. Anim. Sci. 55:545-555.

34. Hidiroglou, M.; Shearer, D.A. 1975. Concentration of manganese in the tissues of cycling and anestrous ewes. Can. J. Comp. Med. 40:306-309.

35. Hunsaker, W.G.; Reiser, B.; Wolynetz, M.S. 1976. Vaginal temperature rhythms in sheep. Int. J. Chronobiol. 4:151-162.

36.* Lodge, G.A.; Heaney, D.P. 1975. Influence of feed allowance during pregnancy on reproductive performance of ewes and growth of suckled and artificially reared lambs. Can. J. Anim. Sci. 55:533-544.

37. Mitchell, D.; Hidiroglou, M.; Jenkins, K.J. 1975. Reproductive performance in ewes on a low-selenium diet. Can. J. Anim. Sci. 55:513-517.

38. Peters, H.F.; Shrestha, J.N.B.; Heaney, D.P. 1976. Purebred and crossbred performance of paternal half-sibs in lamb growth traits. Can. J. Genet. Cytol. 18:571 (Abstract).

39.* Shrestha, J.N.B.; Corbin, B.S.; Gavora, J.S.; Hackett, A.J.; Harris, D.L.; Heaney, D.P.; Langford, G.A.; Peters, H.F.; Reid, S.M. 1976. Developing a sheep information processing system. J. Anim. Sci. 42:1343-1344 (Abstract).

40. Tsang, C.P.W. 1976. Metabolism of 4-^{14}C-estrone by sheep erythrocytes around the time of parturition. Can. J. Biochem. 54:666-669.

1977-78

41. Ainsworth, L.; Hackett, A.J.; Heaney, D.P.; Langford, G.A.; Peters, H.F. 1977. A multidisciplinary approach to the development of controlled breeding and intensive production systems for sheep. Proc. Symp. Management of Reproduction in Sheep and Goats. Univ. Wisconsin, Madison, WI. pp. 101-108.

42.* Ainsworth, L.; Hackett, A.J.; Heaney, D.P.; Langford, G.A.; Peters, H.F. 1977. Canadian systems ... controlled breeding and intensive production. Sheep Breeder and Sheepman 97(12):14-20.

43. Ainsworth, L.; Hackett, A.J.; Heaney, D.P.; Langford, G.A.; Peters, H.F. 1978. ARI - an overview. Sheep Can. 3(2):15-19, and 3(3):6-9.

44. Hidiroglou, M. 1977. Effect of diet on the metabolism of labelled tocopherol in sheep. Br. J. Nutr. 37:215-225.

45. Hidiroglou, M.; Ho, S.K.; Standish, J.F. 1978. Effects of dietary manganese levels on reproductive performance of ewes and on tissue mineral composition of ewes and day-old lambs. Can. J. Anim. Sci. 58:35-41.

46. Ivan, M. 1977. A new method for re-entrant cannulation of the duodenum in sheep. Can. J. Anim. Sci. 57:225-227.

47. Tsang, C.P.W. 1978. Plasma levels of estrone sulfate, free estrogens and progesterone in the pregnant ewe throughout gestation. Theriogenology 10:97-110.

1979

48. Ainsworth, L.; Hackett, A.J.; Heaney, D.P.; Langford, G.A.; Peters, H.F.; Shrestha, J.N.B. 1979. Intensive rearing systems for sheep production. Pages 610-617 in Luchok, J. ed., Hill Lands-Proceedings of an International Symposium. West Virginia University Books, Office of Publications, Morgantown, WV.

49. Hackett, A.J.; Inskeep, E.K.; Robertson, H.A.; Shrestha, J.N.B.; Wolynetz, M.S. 1979. Comparison of artificial insemination and natural mating on reproductive performance of five strains of sheep during the anestrous season in an intensive system. Can. J. Anim. Sci. 59:675-683.

50. Hidiroglou, M. 1979. Manganese in ruminant nutrition. A review. Can. J. Anim. Sci. 59:217-236.

51. Hidiroglou, M. 1979. Trace element deficiencies and fertility in ruminants. A review. J. Dairy Sci. 62:1195-1206.

52. Hunsaker, W.G.; Wolynetz, M.S. 1979. Vaginal temperature and eating, drinking, standing and walking activity rhythms in four anestrous Finnish-Landrace ewes. Can. J. Anim. Sci. 59:11-23.

67. Hidiroglou, M. 1980. Trace elements in the fetal and neonate ruminant: A review. Can. Vet. J. 21:328-335.

68.* Ivan, M.; Hidiroglou, M. 1980. The Ottawa plastic metabolism cage for sheep. Can. J. Anim. Sci. 60:539-541.

69. Ivan, M.; Hidiroglou, M. 1980. Effect of dietary manganese on growth and manganese metabolism in sheep. J. Dairy Sci. 63:385-390.

70.* Langford, G.A.; Fiser, P.S. 1980. Influence of storage temperature and duration of storage on the fertilizing capacity of extended ram semen. J. Anim. Sci. 51(Suppl. 1):295 (Abstract).

71.* Langford, G.A.; Hackett, A.J. 1980. Dose related effects of PMSG in breeding confined sheep by artificial insemination. Can. J. Anim. Sci. 60:562-563 (Abstract).

72.* Langford, G.A.; Marcus, G.J.; Hackett, A.J.; Ainsworth, L.; Wolynetz, M.S. 1980. Influence of estradiol-17β on fertility in confined sheep inseminated with frozen semen. J. Anim. Sci. 51:911-916.

73. Robertson, H.A.; Chan, J.S.D.; Hackett, A.J.; Marcus, G.J.; Friesen, H.G. 1980. The diagnosis of pregnancy in the ewe at mid-gestation. Anim. Reprod. Sci. 3:69-71.

1981

74. Ainsworth, L.; Heaney, D.P.; Langford, G.A.; Hackett, A.J.; Fiser, P.S.; Shrestha, J.N.B. 1981. The Use of Progestagen Impregnated Intravaginal Sponges and Artificial Insemination in Controlled Reproduction Programs for Sheep. Suppl. Tech. Bull. No. 2., Agric. Can., Anim. Res. Cent., Ottawa, Ont. 9 pp.

75.* Fiser, P.S.; Ainsworth, L.; Langford, G.A. 1981. Effect of osmolality of skim-milk diluents and thawing rate on cryosurvival of ram spermatozoa. Cryobiology 18:399-403.

76. Fiser, P.S.; Langford, G.A. 1981. The effect of sodium pentobarbital and storage time on preservation of ram spermatozoa motility at 5°C. Can. J. Anim. Sci. 61:847-851.

77.* Hackett, A.J.; Langford, G.A.; Robertson, H.A. 1981. Fertility of ewes after synchronization of estrus with prostaglandin $F_{2\alpha}$ and artificial insemination. Theriogenology 15:599-603.

78.* Hackett, A.J.; Robertson, H.A.; Penner, P.; McLaughlin, G.R. 1981. Comparison of two methods of synchronizing estrus and subsequent lambing in a commercial sheep flock. Can. J. Anim. Sci. 61:67-72.

79.* Hackett, A.J.; Robertson, H.A.; Wolynetz, M.S. 1981. Effects of prostaglandin $F_{2\alpha}$ and pregnant mares' serum gonadotrophin (PMSG) on the reproductive performance of flurogestone acetate-PMSG-treated ewes. J. Anim. Sci. 53:154-159.

80.* Hackett, A.J.; Wolynetz, M.S. 1981. Comparison of natural mating and artificial insemination on reproductive performance of three strains of sheep housed in total confinement. Can. J. Anim. Sci. 61:907-912.

81.* Heaney, D.P.; Hartin, K.; Shrestha, J.N.B.; Ainsworth, L.; Fiser, P.S.; Langford, G.A. 1981. An attempt to eradicate Maedi-Visna in sheep by hysterectomy. J. Anim. Sci. 53(Suppl. 1):181 (Abstract).

82. Hidiroglou, M. 1981. Copper Deficiency in Ruminants. Publ. 1723/E. Agric. Can., Ottawa, Ont. 18 pp.

83. Hidiroglou, M.; Knipfel, J.E. 1981. Maternal-fetal relationship of copper, manganese, and sulfur in ruminants. A review. J. Dairy Sci. 64:1637-1647.

84. Ivan, M. 1981. Distribution of radiomanganese in the rumen of sheep. Can. J. Physiol. Pharmacol. 59:76-83.

85.* Ivan, M.; Johnston, D.W. 1981. Reentrant cannulation of the small intestine in sheep: cannula and surgical method. J. Anim. Sci. 52:849-856.

86. Ivan, M.; Lamand, M.; Kelleher, C.A.; Mason, J. 1981. Exchange of digesta via duodenal cannula in sheep, a technique useful for absorption studies with labelled compounds. Ann. Rech. Vet. 12:379-383.

87.* Ivan, M.; Veira, D.M. 1981. Effects of dietary protein on the solubilities of manganese, copper, zinc and iron in the rumen and abomasum of sheep. Can. J. Anim. Sci. 61:955-959.

88.* Leger, D.A.; Gowe, R.S. 1981. Animal Research Centre Research Farm, Second Edition. Agric. Can., Anim. Res. Cent., Ottawa, Ont. 110 pp.

89. Marcus, G.J. 1981. Prostaglandin formation by the sheep embryo and endometrium as an indication of maternal recognition of pregnancy. Biol. Reprod. 25:56-64.

90. Marcus, G.J.; Hackett, A.J.; Robertson, H.A. 1981. Ram-induced synchronization of estrus in confined ewes under controlled lighting. Can. J. Anim. Sci. 61:833-837.

91. Veira, D.M.; Ivan, M. 1981. Digestion of corn and alfalfa silages in the stomach and small intestine of sheep prepared with two re-entrant cannulas. Can. J. Anim. Sci. 61:113-119.

1982

92. Ainsworth, L.; Lachance, R.; Labrie, F. 1982. Effect of GnRH induced endogenous luteinising hormone release and exogenous progestogen treatment on ovarian activity in the postpartum ewe. J. Anim. Sci. 54:998-1004.

93.* Ainsworth, L.; Wolynetz, M.S. 1982. Synchronization of estrus and reproductive performance of ewes treated with synthetic progestogens administered by subcutaneous ear implant or by intravaginal sponge pessary. J. Anim. Sci. 54:1120-1127.

94.* Fiser, P.S.; Ainsworth, L.; Fairfull, R.W. 1982. Cryosurvival of ram spermatozoa in hypertonic and isotonic diluents. Can. J. Anim. Sci. 62:425-428.

95.* Hackett, A.J. 1982. Effect of dose of pregnant mares' serum gonadotrophin on the reproductive performance of ewes synchronized for estrus and housed in total confinement. Can. J. Anim. Sci. 62:291-294.

96.* Hackett, A.J.; Dwyer, R.J.; Robertson, H.A.; Wolynetz, M.S. 1982. Reproductive performance of hormonally treated sheep maintained year-round in a controlled-light environment. Can. J. Anim. Sci. 62:1109-1117.

97. Hackett, A.J.; Wolynetz, M.S. 1982. Reproductive performance of totally confined sheep bred with semen extended in a lactose-egg yolk-glycerol buffer and stored at 5°C. Can. J. Comp. Med. 46:327-333.

98.* Hackett, A.J.; Wolynetz, M.S. 1982. Effectiveness of photoperiod stimulation on reproductive performance of sheep housed continuously indoors on an accelerated breeding schedule. Can. J. Comp. Med. 46:400-404.

99.* Hackett, A.J.; Wolynetz, M.S. 1982. Effect of PMSG on the reproductive performance of totally confined ewes bred at synchronized estrus. Theriogenology 17:215-221.

100.* Hackett, A.J.; Wolynetz, M.S. 1982. Reproductive performance of confined sheep in an accelerated controlled breeding program under two lighting regimes. Theriogenology 18:621-628.

101.* Heaney, D.P.; Shrestha, J.N.B.; Peters, H.F. 1982. Performance of lambs fed milk replacers having two levels of fat. Can. J. Anim. Sci. 62:837-843.

102.* Heaney, D.P.; Shrestha, J.N.B.; Peters, H.F. 1982. Potential alternatives to lamb milk replacer for the artificial rearing of lambs. Can. J. Anim. Sci. 62:1135-1142.

103.* Heaney, D.P.; Shrestha, J.N.B.; Peters, H.F. 1982. Rapeseed oil versus coconut oil as a source of fat for lamb milk replacers. Can. J. Anim. Sci. 62:1241-1243.

104. Hidiroglou, M.; Williams, C.J.; Hackett, A.J. 1982. Plasma levels of copper, iron and zinc during the estrus cycle of the ewe. Int. J. Vitam. Nutr. Res. 52:75-79.

105. Ivan, M.; Veira, D.M. 1982. Duodenal flow and soluble proportions of zinc, manganese, copper and iron in the rumen fluid and duodenal digesta of faunated and defaunated sheep. Can. J. Anim. Sci. 62:979-982.

106.* Langford, G.A. 1982. Influence of PMSG and time of artificial insemination on fertility of progestogen-treated sheep in confinement. J. Anim. Sci. 54:1205-1211.

107.* Langford, G.A.; Gabler, S.; Ainsworth, L.; Wolynetz, M.S. 1982. Reproductive response of progestogen-treated sheep in confinement to a single and double insemination. J. Anim. Sci. 54:12-17.

108.* Langford, G.A.; Marcus, G.J. 1982. Influence of sperm number and seminal plasma on fertility of progestogen-treated sheep in confinement. J. Reprod. Fertil. 65:325-329.

109. Poncet, C.; Ivan, M.; Leveille, M. 1982. Electromagnetic measurements of duodenal digesta flow in cannulated sheep. Reprod. Nutr. Dev. 22:651-660.

110. Shrestha, J.N.B. 1982. Measurement and evaluation of wool traits. Sheep Can. 7(2):10-12.

111.* Shrestha, J.N.B.; Ainsworth, L.; Heaney, D.P.; Smith, A.N. 1982. Application of controlled reproduction to sheep flocks in Newfoundland. Can. J. Anim. Sci. 62:679-687.

112. Shrestha, J.N.B.; Heaney, D.P.; Peters, H.F. 1982. Effect of age of ewe, sex of lamb, litter size at birth and rearing on lamb growth. Canadex 430.41.

113.* Shrestha, J.N.B.; Peters, H.F.; Heaney, D.P. 1982. Growth performance of lambs sired by rams of the East Friesian, Finnish Landrace, Ile de France and Suffolk breeds. Can. J. Anim. Sci. 62:689-697.

114. Shrestha, J.N.B.; Peters, H.F.; Heaney, D.P. 1982. Growth performance of lambs sired by East Friesian, Finnish Landrace, Ile de France and Suffolk rams. Sheep Can. 7(1):3-5.

115.* Smith, E.G.; Howell, W.E.; Lee, G.E.; Shrestha, J.N.B. 1982. The Economics of Intensive Sheep Production. Tech. Bull. No. 4., Agric. Can., Anim. Res. Cent., Ottawa, Ont. 73 pp.

116. Veira, D.M.; Ivan, M. 1982. The effect of dietary protein on digestion and fermentation in the gastrointestinal tract of sheep. Ann. Rech. Vet. 13:213-220.

1983

117.* Ainsworth, L.; Lachance, R.; Labrie, F. 1983. Effects of progestogen treatments and PMSG on the induction of the preovulatory LH discharge in ewes. Anim. Reprod. Sci. 5:281-286.

118.* Ainsworth, L.; Shrestha, J.N.B. 1983. Effect of type of intravaginal progestogen treatment on estrous response and reproductive performance of ewes. Theriogenology 19:869-875.

119.* Fiser, P.S.; Fairfull, R.W. 1983. Effects of changes in photoperiod on freezability of ram spermatozoa. Cryobiology 20:684-689.

120. Hackett, A.J.; Hidiroglou, M. 1983. Effects of PMSG on progesterone levels in ewes treated with fluorogestone acetate or prostaglandin $F_{2\alpha}$. Anim. Reprod. Sci. 6:191-197.

121.* Heaney, D.P.; Shrestha, J.N.B.; Peters, H.F. 1983. Effects of post-weaning protein regimens and urea on the performance of intensively reared lambs. Can. J. Anim. Sci. 63:631-641.

122. Langford, G.A. 1983. Artificial insemination for sheep. Canadex 430.36.

123. Langford, G.A. 1983. Insémination artificielle ovine. Le Moutonnier/ Chèvre - Québec 10:11.

124.* Langford, G.A.; Marcus, G.J.; Batra, T.R. 1983. Seasonal effects of PMSG and number of inseminations on fertility of progestogen-treated sheep. J. Anim. Sci. 57:307-312.

125.* Reid, W.S.; Ivan, M.; Buckley, D.J. 1983. An automatic digesta sampler for sheep. J. Agric. Eng. Res. 28:79-87.

126.* Shrestha, J.N.B.; Ainsworth, L.; Heaney, D.P. 1983. Influence of breed on reproductive performance of ewes treated with fluorogestone-acetate-impregnated intravaginal sponge and pregnant mare's serum gonadotrophin during the breeding season. Can. J. Anim. Sci. 63:1-6.

127. Shrestha, J.N.B.; Ainsworth, L.; Heaney, D.P.; Smith, A.N. 1983. Controlled sheep breeding procedures in Newfoundland. Sheep Can. 8(1):9-11.

128.* Shrestha, J.N.B.; Fiser, P.S.; Langford, G.A.; Heaney, D.P. 1983. Influence of breed, birth date, age and body weight on testicular measurements of growing rams maintained in a controlled environment. Can. J. Anim. Sci. 63:835-847.

129.* Shrestha, J.N.B.; Peters, H.F.; Heaney, D.P. 1983. Inheritance of weights of lambs reared artificially or with their dams. Can. J. Anim. Sci. 63:263-268.

130.* Veira, D.M.; Ivan, M.; Jui, P.Y. 1983. Rumen ciliate protozoa: Effects on digestion in the stomach of sheep. J. Dairy Sci. 66:1015-1022.

1984

131.* Ainsworth, L.; Downey, B.R. 1984. A controlled internal drug releasing device containing progesterone for estrus synchronization in sheep. Proc. 10th Int. Congr. Anim. Reprod. Artif. Insem., Univ. Illinois. III:302.

132. Bernon, D.E.; Shrestha, J.N.B. 1984. Sexual activity patterns in rams. Can. J. Comp. Med. 48:42-46.

133.* Fiser, P.S.; Batra, T.R. 1984. Effect of equilibration time at 5°C and photoperiod on survival of ram spermatozoa frozen in straws. Can. J. Anim. Sci. 64:777-780.

134.* Fiser, P.S.; Fairfull, R.W. 1984. The effect of glycerol concentration and cooling velocity on cryosurvival of ram spermatozoa frozen in straws. Cryobiology 21:542-551.

135.* Fortin, A.; Shrestha, J.N.B. 1984. Use of ultrasound to predict the composition of 115 day old ram lambs. Proc. 35th Annu. Meet. Eur. Assoc. Anim. Prod. p. S6 a.1 (Abstract).

136.* Hackett, A.J.; Wolynetz, M.S. 1984. Fertility of ewe lambs maintained indoors year-round on an accelerated breeding program. J. Anim. Sci. 59:1129-1134.

137.* Heaney, D.P.; Shrestha, J.N.B.; Peters, H.F. 1984. Postweaning performance of artificially reared lambs weaned at 21 vs 28 days of age under two postweaning housing regimens. Can. J. Anim. Sci. 64:667-674.

138. Heaney, D.P.; Shrestha, J.N.B.; Peters, H.F. 1984. Reducing the cost of milk replacer for the artificial rearing of lambs. Sheep Can. 8(4):7.

139. Heaney, D.P.; Shrestha, J.N.B. 1984. Management tips for reducing artificial rearing costs for lambs. Sheep Can. 9(4):3-4.

140.* Hidiroglou, M.; Heaney, D.P.; Hartin, K.E. 1984. Copper poisoning in a flock of sheep. Copper excretion patterns after treatment with molybdenum and sulfur or penicillamine. Can. Vet. J. 25:377-382.

141. Hidiroglou, M.; Knipfel, J. 1984. Plasma and milk concentrations of vitamin D_3 and 25-hydroxyvitamin D_3 following intravenous injection of vitamin D_3 or 25-hydroxyvitamin D_3. Can. J. Comp. Med. 48:78-80.

142. Hidiroglou, M.; Williams, C.J. 1984. Vitamin D_3 levels in certain sheep tissues at various times after the intramuscular administration of vitamin D_3. Int. J. Vitam. Nutr. Res. 54:17-23.

143.* Langford, G.A. 1984. Ultrasonic pregnancy testing in sheep bred at synchronized estrus. Canadex 430.39.

144. Langford, G.A. 1984. Reproductive performance of confined ewe lambs bred by artificial insemination. Proc. 10th Int. Congr. Anim. Reprod. Artif. Insem., Univ. Illinois. III:371.

145. Langford, G.A. 1984. Entrevue: Insémination artificielle ovine. Le Moutonnier/Chèvre - Québec 13:30-31.

146. Langford, G.A. 1984. Ultrasonic pregnancy testing in sheep bred at synchronized estrus. Sheep Can. 9(2):3-4.

147.* Langford, G.A.; Hackett, A.J.; Marcus, G.J. 1984. Studies on ram sperm penetration in bovine cervical mucus. Proc. 10th Int. Congr. Anim. Reprod. Artif. Insem., Univ. Illinois. II:58.

148.* Langford, G.A.; Shrestha, J.N.B.; Fiser, P.S.; Ainsworth, L.; Heaney, D.P.; Marcus, G.J. 1984. Improved diagnostic accuracy by repetitive ultrasonic pregnancy testing in sheep. Theriogenology 21:691-698.

149.* Poncet, C.; Ivan, M. 1984. Effect of duodenal cannulation in sheep on the pattern of gastroduodenal electrical activity and digestive flow. Reprod. Nutr. Dev. 24:887-902.

150. Shrestha, J.N.B.; Fiser, P.S.; Ainsworth, L. 1984. Raddle markings and presence of spermatozoa in vaginal smears as predictors of ewes lambing to matings at the synchronized estrus. Can. J. Anim. Sci. 64:563-568.

151.* Shrestha, J.N.B.; Heaney, D.P.; Fiser, P.S.; Langford, G.A. 1984. Influence of breed, birth date, age and body weight on linear body measurements of growing rams maintained in a controlled environment. Can. J. Anim. Sci. 64:279-291.

152.* Veira, D.M.; Ivan, M.; Jui, P.Y. 1984. The effect of ciliate protozoa on the flow of amino acids from the stomach of sheep. Can. J. Anim. Sci. 64(Suppl.):22-23.

1985

153.* Ainsworth, L. 1985. Effects of norgestomet-implants and fluorogestone acetate-impregnated sponges on oestrous cycle length and luteal function of ewes. Anim. Reprod. Sci. 9:63-73.

154. Ainsworth, L.; Fiser, P.S.; Heaney, D.P.; Langford, G.A.; Shrestha, J.N.B. 1985. Intensive husbandry of fecund sheep. Pages 399-409 in Land, R.B.; Robinson, D.W. eds., Genetics of Reproduction in Sheep. Butterworths, London, England.

155.* Ainsworth, L.; Shrestha, J.N.B. 1985. Effect of PMSG dosage on the reproductive performance of adult ewes and ewe lambs bred at a progestogen-PMSG synchronized estrus. Theriogenology 24:479-487.

156.* Buckley, D.J.; Veira, D.M.; Nicholls, C.F.; Ivan, M.; St. Amour, G. 1985. An automated device for controlled feeding of sheep in cages or pens. Can. J. Anim. Sci. 65:273-277.

157. Hackett, A.J.; Wolynetz, M.S. 1985. Reproductive performance of Finnish Landrace and Suffolk sheep maintained indoors year-round. J. Anim. Sci. 60:334-341.

158.* Heaney, D.P.; Hidiroglou, M.; Shrestha, J.N.B.; Ho, S.K. 1985. Effects of dietary calcium and phosphorus concentrations and intramuscular injections of vitamin D_3 on growth and serum parameters of lambs reared in a controlled environment. Can. J. Anim. Sci. 65:163-173.

159.* Heaney, D.P.; Shrestha, J.N.B. 1985. Effects of warm versus cold milk replacers and of free-choice hay postweaning on performance of artificially reared lambs. Can. J. Anin. Sci. 65:871-878.

160. Hidiroglou, M.; Williams, C.J.; Proulx, J.G. 1985. Plasma vitamin D_3 response in cattle and sheep exposed to ultraviolet radiation. Int. J. Vitam. Nutr. Res. 55:41-46.

161.* Ivan, M.; Buckley, D.J.; St. Amour, G.; Nicholls, C.F.; Veira, D.M. 1985. Fully automated system for aerobic or anaerobic sampling of duodenal digesta in sheep or cattle equipped with duodenal reentrant cannulas. J. Anim. Sci. 60:1359-1366.

162. Ivan, M.; Veira, D.M. 1985. Effects of copper sulfate supplement on growth, tissue concentration, and ruminal solubilities of molybdenum and copper in sheep fed low and high molybdenum diets. J. Dairy Sci. 68:891-896.

163.* Ivan, M.; Veira, D.M. 1985. Copper sulfate as a dietary supplement to prevent molybdenum toxicity or copper deficiency in sheep. Canadex 430.65.

164.* Langford, G.A. 1985. Effect of duration and frequency of change in photoperiod on sperm concentration, sperm motility and scrotal size of rams kept year-round in controlled environments. J. Androl. 6(Suppl. 1): 139 (Abstract).

165.* Langford, G.A.; Ainsworth, L. 1985. Manipulation of artificial photoperiods to maintain testosterone production, testis size and semen quality year-round in rams. Biol. Reprod. 32(Suppl.1):83 (Abstract).

166.* Langford, G.A.; Ainsworth, L. 1985. Significance of scrotal size during testicular redevelopment in relation to semen quality in rams responding to artificial photoperiods. J. Anim. Sci. 61(Suppl.1):413 (Abstract).

167.* Shrestha, J.N.B.; Heaney, D.P. 1985. Genetic and phenotypic parameters of early growth traits of lambs reared artificially in a controlled environment. Can. J. Anim. Sci. 65:37-49.

168. Shrestha, J.N.B.: Vesely, J.A.; Chesnais, J.P. 1985. Genetic and phenotypic parameters for daily gain and body weights in Suffolk lambs. Can. J. Anim. Sci. 65:575-582.

1986

169.* Fiser, P.S.: Fairfull, R.W. 1986. Combined effects of glycerol concentration, cooling velocity and osmolality of skim milk diluents on cryopreservation of ram spermatozoa. Theriogenology 25:473-484.

170.* Fiser, P.S.: Fairfull, R.W.: Marcus, G.J. 1986. The effect of thawing velocity on survival and acrosomal integrity of ram spermatozoa frozen at optimal and suboptimal rates. Cryobiology 23:141-149.

171. Fortin, A.: Shrestha, J.N.B. 1986. In vivo estimation of carcass meat by ultrasound in ram lambs slaughtered at an average weight of 37 kg. Anim. Prod. 43:469-475.

172.* Heaney, D.P.: Shrestha, J.N.B. 1986. Effects of soyflour in milk replacer on the performance of artificially reared lambs. Can. J. Anim. Sci. 67:(IN PRESS).

173.* Ivan, M.: Veira, D.M.: Kelleher, C.A. 1986. The alleviation of chronic copper toxicity in sheep by ciliate protozoa. Br. J. Nutr. 55:361-367.

174.* Langford, G.A. 1986. Influence of body weight and number of inseminations on fertility of progestogen-treated ewe lambs raised in controlled environments. J. Anim. Sci. 62:1058-1062.

175.* Shrestha, J.N.B.: Fortin, A.: Heaney, D.P. 1986. Genetic and phenotypic parameters of carcass traits in ram lambs reared artificially in a controlled environment. Can. J. Anim. Sci. 66:905-914

7. ADDITIONAL REFERENCE MATERIAL

Alberta Sheepman's Manual. 1978. Alberta Agriculture, Edmonton, Alberta.

Genetics of Reproduction in Sheep. 1985. Land, R.B.; Robinson, D.W. eds. Butterworths, London, England.

Nutrient Requirements of Sheep, Sixth Revised Edition. 1985. National Academy Press, Washington, DC.

Ontario Shepherd's Manual. Ontario Ministry of Agriculture and Food, Toronto, Ontario.

Research to Increase Lamb Production in Canada. 1982. Prepared by Animal Research Centre in cooperation with Communications Branch, Agriculture Canada. 16mm., color, sound film, 26 min.

Sheep and Goat Production. 1982. Coop, J.E. ed. Elsevier, New York, NY.

Sheep Breeding - Second Edition. 1979. Tomes, G.L.; Robertson, D.E.; Lightfoot, R.J.; Haresign, W. eds. Butterworths, London, England.

Sheep Nutrition and Management. 1977. U.S. Feed Grains Council, London, England.

Sheep Production. 1983. Haresign, W. ed. Butterworths, London, England.

The Control and Manipulation of Reproduction in Sheep. 1983. Pages 155-287 in Gordon, I. ed., Controlled Breeding in Farm Animals. Pergamon Press, Oxford, England.

The Management and Diseases of Sheep. 1979. The British Council and The Commonwealth Agricultural Bureaux, London, England.

The Sheepman's Production Handbook. Second Edition. 1975. Sheep Industry Development Program, Inc. Denver, CO.

Toujours Plus D'Agneaux ou la Reproduction Programmée. 1979. Cinémathèque Searle, Département Vétérinaire, Laboratoires Searle, Montrouge, France. 16 mm., color, sound film, 28 min.

8. INFORMATION BULLETINS RELATED TO SHEEP PUBLISHED BY AGRICULTURE CANADA

Sheep diseases in Canada. Publication 1481/E.
This publication informs sheep producers of the characteristics of the more common diseases and infestations of sheep.

Canadian lamb. Publication 1501/E.
This publication provides information on the buying, storing, preparation and cooking of lamb.

Artificial rearing of young lambs. Publication 1507/E.
This publication describes milk replacer formulations, feeding and management systems for raising lambs artifically from 1 day of age.

Sheep production and marketing. Publication 1582/E.
This publication serves as a practical guide to sheep production and marketing in Canada. Topics include management techniques, marketing, breed characteristics, flock health, buildings and equipment.

Wool production in Canada. Publication 1763/E.
This publication describes the characteristics, harvesting and marketing of wool.

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9. CANADA PLAN SERVICE

The Canada Plan Service is a cooperative Federal/Provincial organization which prepares construction plans, descriptive leaflets and information bulletins on how to construct modern farm buildings, livestock housing systems, storages and farmstead equipment for Canadian farmers and producers.

The Service has designed a wide variety of sheep buildings and equipment. The detailed descriptions, catalogues and drawings can be obtained from your local provincial agricultural engineer or extension advisor.